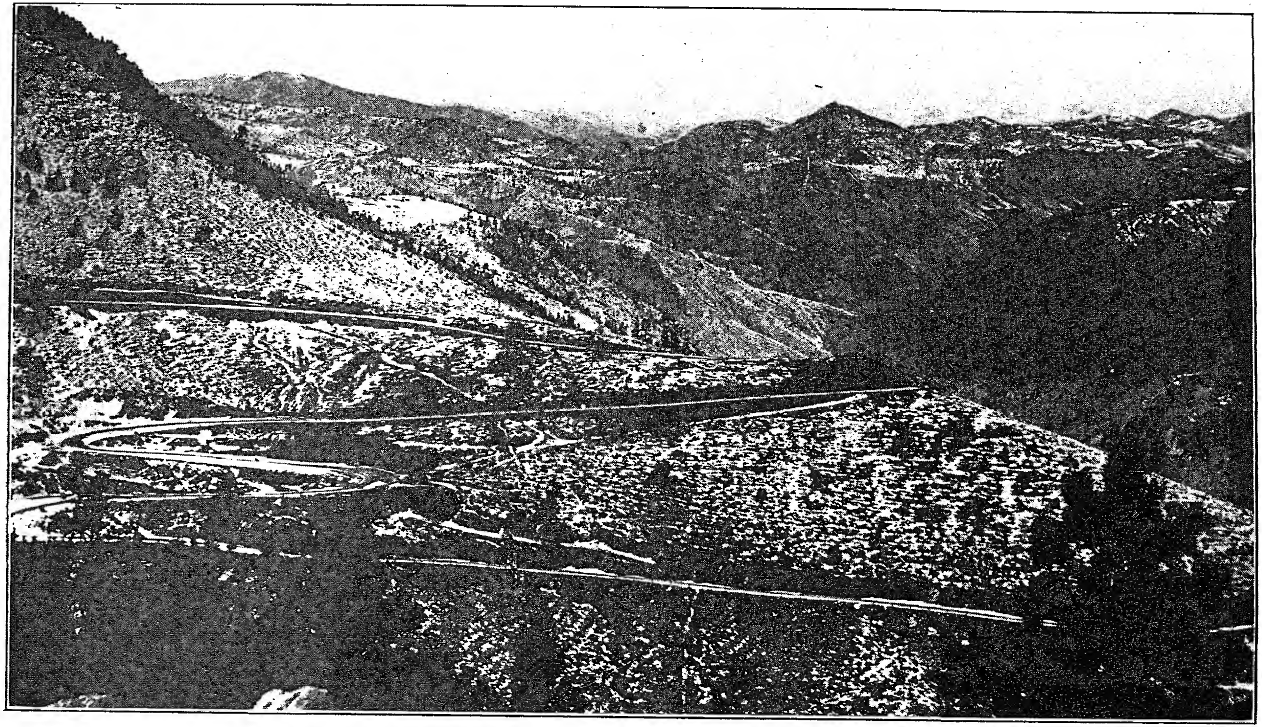

FIG. 1.—Well-located mountain road near Denver, Colorado.

Frontispiece.

THE LOCATION, GRADING AND DRAINAGE OF HIGHWAYS

A Concise Discussion of General Principles Illustrated by Current and Recommended Practice

BY

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PREFACE

This book is the first of a series of four volumes presenting the road problem from the standpoint of the constructing engineer. It is intended for the use of students and practicing engineers. Each book will be complete in itself and will deal with a well defined portion of the general problem.

The first book covers a discussion of general principles governing the policy of highway programs such as: the scope of the program, general character of the system, classification, layout, appropriation estimates, fundamental principles of design and reasonable economy in design. It develops the detail theory of economic location and grade line design from the standpoints of both horse and motor traffic. It discusses Cross Sections, Roadway Widths, Right of Way and Drainage. The intention is for this volume to cover concisely but fully the principles of design of the relatively permanent features of highway construction. Theory is developed but used largely as a basis for judgement. The data and discussions of theory are made as definite as possible and are illustrated by current and recommended practice. Emphasis is laid on the desirability of making appropriations accomplish as much as possible and the engineering means to this end are indicated. An effort has been made to show the value and limitations of scientific engineering in relation to the road problem.

The other volumes of the series are in preparation. They will cover the selection of pavement type, methods of construction, Maintenance and Reconstruction; also the detail methods of field and office work and Construction Engineering and Inspection.

The co-operation of Highway Engineers and State Departments is acknowledged throughout the text. Special acknowledgement is made of the constructive criticism of this manuscript by Mr. Percy Waller, Mr. Thomas Mahaney, Mr. J. Y. McClintock and Mr. H. G. Hotchkiss.

A number of tables and some of the text have been adapted from the Harger and Bonney Highway Engineers' Handbook.

W. G. HARGER.

ROCHESTER, N. Y., 1920.

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THE LOCATION, GRADING AND DRAINAGE OF HIGHWAYS

CHAPTER I

GENERAL PRINCIPLES OF ECONOMIC HIGHWAY DESIGN

The Relation of Highway Engineering to The Road Problem.—The advantages of improved highways have been so well demonstrated that it is not at all difficult to inaugurate improvement programs up to the limit of the financial ability of the communities. The reasonable expenditure of appropriations for the actual construction of roads is the pressing problem at this time. From political, business and engineering standpoints it is essential that highway programs shall not be discredited.

Construction work should fulfil as nearly as possible the promises made at the time the appropriation is authorized as these promises are in essence a contract with the community, which if not carried out in good faith react on the promoters and discredit the road movement. The community generally expects a reasonable mileage of serviceable road. If appropriation estimates are based on careful engineering layouts, classifications and cost estimates, the finished construction will usually approximate the proposed program. If no such engineering advice is used the completed work often falls far short of what the taxpayers have a right to expect.

A policy of uniform pavement design utilizing one type of pavement to the extent of excluding other standard and well-recognized types is to be avoided. A distribution of patronage among the various business interests actively engaged in road construction promotes healthy competition and eliminates the needless antagonism of those industries which might be slighted under a uniform policy. Such a distribution of business results from an engineering analysis of the selection of pavement type,

as common sense engineering tends to discourage any policy of uniform pavement selection, not only on account of the danger of raising prices, overloading the capacity of special road material industries, overloading transportation facilities, and slowing down construction progress, but also because various kinds of pavement are needed to meet different road conditions.

Road programs are always subjected to partisan criticism. If they are based on sound engineering principles and the construction controlled by rigid engineering inspection, they are easier to defend and are changed less by successive administrations. The tendency of new administrations to needlessly change policy and methods in the midst of a construction program rarely works out well and while it is impossible to entirely prevent this, any method that helps to stabilize procedure is a move in the right direction. Even from the standpoint of ordinary political expediency reliable engineering is useful.

The value of broad gauge engineering as a basis for highway work is so evident to anyone familiar with the problem that it ought to be generally recognized. Unfortunately it is often not given the weight to which it is entitled. This is partly due to popular prejudice and is partly the fault of the engineering profession. The average citizen and many non-technical road officials consider that the engineer is an unavoidable nuisance and that whatever is spent on engineering is a doubtful investment. They feel that for some reason an engineer is necessary, but they are hazy as to why this is so. They are impressed by the use of a transit or level, but have no respect for broad engineering decisions. They think because roads are a common every day affair that the highway problem is simple and requires no special training. They know that local officials have built most of the roads of the past and see no reason for the scientific analysis of the road problem in the future. They have the local view point of the old piecemeal temporary light traffic programs, which were fairly well handled by local men, and they have no real conception of a unified modern highway system with its range of traffic from light duty to heavy duty. They do not differentiate between the value of mediocre and high-grade engineering; they know that almost anyone can build almost any kind of a road if money enough is provided, but they do not realize that the test of high grade engineering lies in the actual construction of a proper road for less money than would be spent

by a less expert designer. This point of view can be corrected by effort on the part of the engineers and while it handicaps the work at present it adds interest to the game which would otherwise be too easy. As a matter of fact the rapid adoption of State and Federal control of highway programs automatically improves the engineering and financial aspects, although the status of highway engineers is yet far below what it should be. Even the public officials who realize the value of high-grade technical advice either have to consider the popular view or actually prefer mediocre talent on account of lower salaries and the greater freedom that they have to carry out their own pet schemes.

No profession can achieve a high standing unless its members demonstrate a sense of responsibility to the community. In highway work it seems reasonable to hold the engineer responsible for the general scheme and the detail results. If a program is essentially wrong no one knows it better than the engineer and no one can point out the constructive remedy better than he can. If he chooses to subordinate his knowledge and sense of responsibility to policies of political expediency affecting the fundamental value of the improvements the entire profession pays the penalty. If he is content to be a tool he will be treated as a tool. If he has the mental attitude of a subordinate clerk or office boy, he will be ranked as such. The fighting spirit in regard to real essentials is necessary. It is strictly up to the profession. They must throw their influence towards sound finance programs. They must insist on first class construction and the fair treatment of contractors. They must not advocate scientific fads and needlessly excessive refinements in materials or methods which raise the cost of roads beyond reason. They must be as careful not to overdesign as not to underdesign. They must realize their responsibility to the community at large, but not overemphasize the strictly technical part of a highway program.

Any sound engineering policy is based on good common sense which emphasizes the fact that highway engineering and even the actual construction of roads are only a means to an end. The most important people in any road program are the actual road users who serve the community by the operation of vehicles over the completed highways. The actual traffic interests are the most important factor in any proper solution.

It is essential that traffic requirements be carefully analyzed and that caution be used in excessive expenditures for the benefit of a small percentage of the actual road users. That is, the requirements of the average road user should usually outweigh the spectacular requirements of a small number of men, unless these men are willing to pay the additional cost of construction made necessary by the unusual type of vehicle which they operate.

The highway problem is extremely complex and subject to a wide range of local conditions which affect the detail solutions but the general principles are fairly well defined. There are a number of satisfactory ways of solving the details of any problem, provided the general plan is sound and economic principles of design are applied. The important thing is that a comprehensive analysis shall be made and some well-balanced plan carried to a conclusion.

DISCUSSION OF GENERAL PRINCIPLES

The intent of the general discussion is to emphasize the main features of design. For this reason, fine distinctions are not introduced in this chapter as they tend to confuse the argument. Before taking up the detail analysis it is just as well to make a quick survey of the general factors governing policy and to formulate a few fundamental principles on which the scheme of design can be developed.

Road Service.—Service to the community and to the direct user is the object of all road improvements. It is not uncommon for Highway Engineers to forget the road user and the community and think only of a mass of technical detail. Service to the community consists in aiding the improvement of economic and social conditions of rural life and in promoting the development of natural resources. Service to the direct road user lies in providing a means whereby he can get *all the way* to his destination in comparative safety and at the same time haul his load. Roads are intended to get somewhere and not to stop on the way. The fundamental requirement of all highway programs would seem to be the construction of the greatest possible connected mileage of road that will handle existing traffic without too large a maintenance charge. The entire problem of economic design is founded on this premise.

It is not unusual to see large appropriations absorbed by a com-

essential expenditure but encourages necessary expenditures on essential features. To illustrate we may say that a reasonable policy of service requires radically different methods of approach in different localities. Road design ranges from the low-type earth roads of sparsely settled districts to the hard-surfaced pavements of densely populated sections. For these extreme conditions the issues are clear-cut; the first requires the greatest possible mileage with limited funds, and the last the most suitable design *for present conditions* regardless of first cost. Intermediate cases are handled by merging the requirements of the extremes. A reasonable design for any case depends on the needs and re-

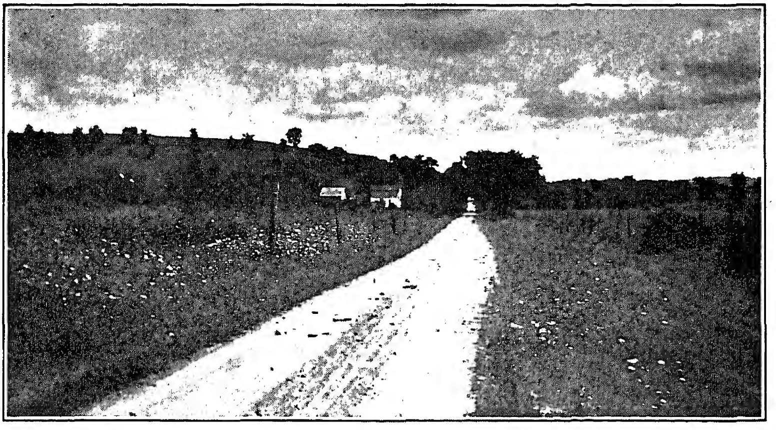


Fig. 4.—Typical single track gravel road (New York state). Very satisfactory for local traffic in agricultural districts. (The third stage of progressive improvement.)

sources of the local community, considered in connection with the importance of the improvement to the general transportation scheme of the country and the outside aid that will be granted on account of its general importance. In pioneer districts mileage is the only important consideration, and a sufficiently cheap type of construction must be adopted to obtain a line of communication to the point desired; an ordinary earth road is all that can be reasonably expected for the greater part of these districts. Scattered agricultural communities require primarily roads that are usable the year around and that will handle ordinary farm traffic; gravel or similar, fairly cheap constructions are the only reasonable solutions for the greater part of these districts.

Densely populated districts with closely located cities require the highest, strongest type of rigid pavements for the main connecting routes and macadam and gravel constructions for the secondary and local roads.

To design a needlessly expensive road even in a rich community is as poor policy as to build a road that will not handle the present traffic. It is not necessary to worry about future traffic. The future has a habit of taking care of itself. The permanent features of construction such as route, alignment, grades, etc. should be designed for the future but the pavement surface is at its best only temporary and extremely expensive pavements are

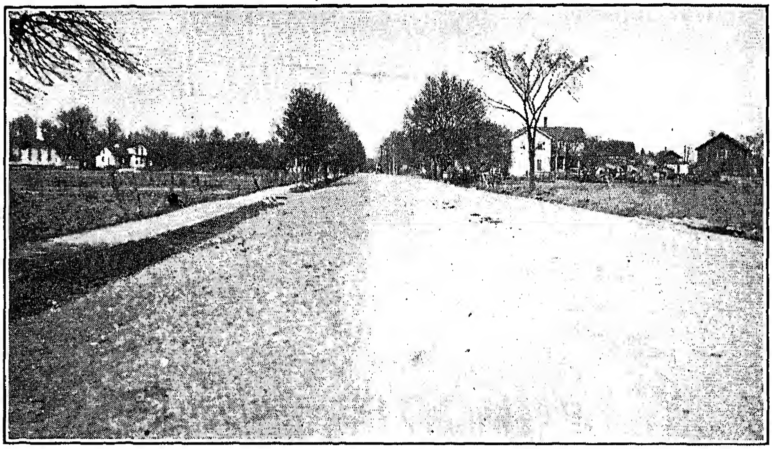


FIG. 5.—Typical penetration bituminous macadam (State Route No. 16 New York). Carries approximately 1500 vehicles per day. Note the easy shoulder slope which adds to the safety of traffic.

not justified unless present traffic demands them. Appropriations for the original construction of improved highways over routes on which the existing roads are poor may well be spent on the principle of mileage service. After a system of reasonably good roads is attained a Reconstruction Program of Boulevards is justified if the money is available from the proper sources. *The community at large can generally afford to shoulder the burden of the original construction of reasonably good roads but it can rarely afford to pay for boulevards. The direct road user can well afford to shoulder the burden of the maintenance of reasonably good roads and he should be given the opportunity of paying for reconstruction if he wants the additional comfort and ease of a boulevard system.*

Some conclusion of this nature governs the decision as to the method of financing various stages of improvement programs.

Demands of Traffic and Their Effect on Design.—To fulfill the principle of service, roads should be located and designed to serve the *great majority of direct users* with the least inconvenience and the fewest restrictions that are feasible, but a few individuals who, for some reason, find it convenient to use extremely heavy unit vehicles, must be ruled off from the majority of the highways. It will be financially impossible for any community to construct and maintain all of its rural highways and bridges without regulation of heavy traffic. Roads like any other engineering struc-

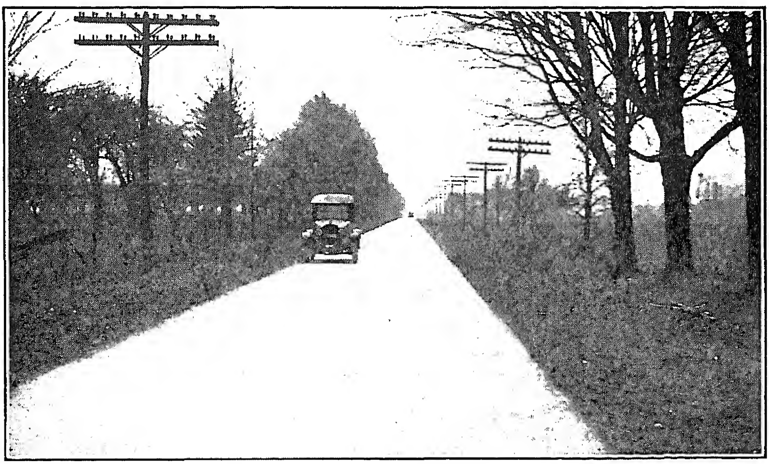


Fig. 6.—Typical rigid pavement highway (Industrial District Ohio). Note the shallow ditch which adds to the safety of traffic.

ture should be built for normal and not for abnormal use. The highway engineer would prefer not to restrict traffic but it is a practical necessity. It is not feasible or desirable to restrict average traffic but we cannot permit a small percentage of the users to operate exceptionally heavy units which if considered in the design of local service roads would raise the total cost of a general road system beyond reason.

The second principle of design appears to be: Traffic regulation is necessary not only to save past investment but also to enable the community to finance any enduring general system of roads and to make economic engineering design possible. The application of this principle hinges on the usual range and popular methods of hauling.

Range of Traffic.—All the available data indicates that probably 90 to 95 per cent. of road traffic can be classed as local service. That is, it has its origin and finish within a comparatively short radius and consists of the hauling of garden truck to cities, produce to shipping points, social visits and short recreational trips. The other 10 per cent. may be classed as long distance traffic consisting of pleasure touring, light passenger cars of commercial travelers and long distance motor hauling of freight between cities. These ratios of general traffic do not, of course, apply to any one road and may be actually reversed on certain special touring routes but they probably apply to the road systems as a whole in most states, counties and towns and they indicate the basis for locating improvements and for apportioning county, state or federal aid. Any highway program to render the greatest service to the community may well be laid out on the principle of serving first the local and second the through traffic.

It is certain that a county that adopts the policy of getting some kind of a road that is usable the year round in front of every farm is nearer right than if it spent the funds for a skeleton system of needlessly high-class roads routed primarily for through traffic. There is no reason why the program should not consider both factors in their proper proportion but the danger has of late years been more often on the side of favoring through traffic to the detriment of local service. *The third principle of design may be formulated as: Local traffic is entitled to first consideration in the location of roads and their design except for a comparatively small mileage of special service highways.* To apply the second and third principles, it is necessary to arrive at a reasonable conclusion in regard to traffic routes and also as to what types of vehicle will probably best serve the great majority of direct road users.

Weight of Traffic.—Twenty years ago road traffic was entirely horse drawn. Today it is largely motor, particularly where an improved road system has been completed. It is safe to say that highway transport on improved roads will be largely by motor vehicles although it is not likely that horse traffic will entirely disappear. Motor traffic for commercial success requires a higher speed and greater unit vehicle load than horse traffic and consequently controls the foundation design and surfacing of the roads of today although in some features of the design

it is probably better to modify this conclusion in order to satisfy the requirements of horse traffic also.

For the usual farming community where the hauls do not exceed 10 to 20 miles to market or shipping points and where each farmer owns his truck all available information indicates that the light ¾- to 2½-ton truck with pneumatic tire equipment will probably be the most popular type for hauling.[1] The popularity of this type seems to be based on a reasonable first cost, moderate upkeep, high speed, comfort and general utility. This kind of truck does not seriously injure any of the improved roads

FIG. 7.—Moderate size general utility truck.

that are in general use provided they are well designed and maintained. Such truck traffic and the usual pleasure car need not be subjected to regulation to the extent of modifying any of their desirable features. That is, probably 90 to 95 per cent. of road users can be served with moderate priced roads.

For long distance motor freight hauling in competition with railroad freight the 5-ton or heavier truck appears to be the logical unit. At the present time, there does not seem to be a large proportion of road mileage that will be subjected to this class of traffic. It is, however, an increasingly important phase of service, but as the conditions which make it economical do not apply

[1] See U. S. Dept. of Agriculture Bulletin No. 919 for data on the use of trucks by farmers.

to large areas a comparatively small number of special service roads ought to satisfy any reasonable demands of such users. Traffic of this kind requires a heavy rigid type of pavement, the shortest possible distance between terminals, the elimination of needless rise and fall, and easy grades. Special service roads should be built but it is reasonable to restrict the operation of heavy trucks or trailer trains to these routes and rule them off of the secondary and feeder roads. Special permits to 5-ton trucks could be granted for a special fee for emergency trips over local service roads during the dry season of the year. Regulations of this nature would not be an unreasonable hardship on the commercial interests manufacturing or using such units as the great field for their popularity is apparently confined largely to city territory or to well-defined hauling routes.

The tractor trailer system is applicable to special conditions but reasonable gross weights and wheel pressures are not a hardship to the manufacturer or user and regulation of these outfits make them feasible for use on special service roads. They do not necessarily require a rigid pavement surface but generally do require a greater road foundation strength than most secondary or feeder roads and should be ruled off of such roads.

It therefore seems feasible to regulate traffic to the point where the community can afford to build improved road systems, without unfairness to the manufacturers of trucks or annoying interference with the choice of the individual in his car. Present sentiment favors the design of secondary and feeder roads on the basis of a 10-ton gross vehicle load, a 7-ton gross back axle load and a wheel pressure per linear inch of tire not exceeding 600 lb. Special service roads may well be designated to carry a gross vehicle load of 15 tons, a 10-ton back axle load and a wheel pressure of 800 lb. per linear inch of width of tire. Practically all authorities are agreed that *heavy traffic must be regulated for both load and speed.* The present sentiment on solid tire truck speed regulation appears to lie between 12 and 15 miles per hour; the effect of speed on impact and the amount of such impact on pavements is under investigation by the U. S. Bureau of Roads.

The fourth principle of design may be assumed to be: the strength of pavement foundations and bridges should be designed for the maximum regulated load for the class of service for which the road is intended. No attempt should be made to reduce construction cost by using a weak foundation.

The practical action of this principle results as a rule in rigid pavement construction on special service roads and in some form of macadam, gravel, sand-clay, or earth roads for the secondary and feeder systems. Under certain conditions of material supply a rigid pavement is desirable even on secondary roads but the case is the exception rather than the rule considering the first principle of design, *Mileage Service*.

INFORMATION TO TRUCK OPERATORS

The essential points in Section 1, par. 282-a of the Highway Law, as enacted by the New York State Legislature of 1920, are as follows:

1. No truck, with load, shall weigh more than twenty-five thousand pounds.
2. No truck body, including load, shall be more than eight feet wide.
3. No truck body, including load, shall be more than twelve feet six inches high.
4. No wheel shall carry more than eight hundred pounds per inch width of tire.

NEW YORK STATE DEPARTMENT OF HIGHWAYS,
FRED'K STUART GREENE,
Commissioner.

Truck Dimensions and Loading

Under the state law of Pennsylvania (1920) commercial vehicles are divided into seven classes. The maximum weights allowed for these classes, including chassis, body and load, are as follows:

Class AA, 7,000 lb.; class A, 11,000 lb.; class B, 15,000 lb.; class C, 20,000 lb.; class D, 24,000 lb.; class C and F, 26,000 lb.

No commercial vehicles may travel at a rate of speed in excess of that shown in the following table:

Class AA, 20 miles per hour; class A, 20 miles; class B, 18 miles; class C, 15 miles; class D, 15 miles; class E, 12 miles; class F, 10 miles.

Truck Speeds

Pavement Type.—The use of different pavements for different service can be well shown by a quotation from a recent article on a general scheme of Highway Improvement in Monroe County, New York.[1] Monroe County has an unusually good general highway system. J. Y. McClintock, the County Superintendent of Highways, is one of the most level headed highway engineers in the country today. The following material is briefed from his report (see Fig. 14, opposite page 42, for map of this territory):

Monroe County has an area of:	650 square miles
A total population of approximately	350,000
A population, City of Rochester, approx.	280,000
A population outside of the city, approx.	70,000
An assessed valuation (real) of	$327,000,000
A total mileage of roads, outside of the city and villages of	1,360 approx.
A total mileage of improved state roads of	330 approx.
A total mileage of improved town roads of	700 approx.
A total mileage of unimproved roads of	330 approx.
The total number of motor licenses	22,000 approx.
The total number of truck licenses	3,000 approx.
(Approximately 85 per cent. of these trucks are less than 2-ton rated capacity).	

The demands of traffic in this county are more extreme than for most localities except in metropolitan areas. The county has had all kinds of pavements in use under a great range of traffic for a number of years and we feel that we have sufficient data in regard to maintenance costs and the life of surfacings to come to a reasonable conclusion as to the future policy of completing the road system. The conclusions are summarized as follows:

"We advocate the original construction of cross roads of thick modern waterbound macadam utilizing local materials as much as possible and maintained by surface oiling.

"We advocate the original construction of our secondary radial roads, of penetration, bituminous macadam, utilizing local materials to their fullest reasonable extent and maintained by surface oiling.

"We advocate the construction of our Main Trunk Line heavy hauling roads of rigid pavements, using the best materials that can be obtained, but varying the type to secure, in each case, the cheapest first cost pavement, always considering the possible use of local materials proper for the type of road in question. For these roads we have no choice

[1] This particular district is a rich highly developed country. For pioneer territory or scattered agricultural districts the same general principle applies but relatively cheaper road surfaces must be used.

between cement concrete, brick, sheet asphalt, asphalt block, or stone block on concrete bases.

"We advocate the gradual resurfacing of the heavier traffic macadam roads with Topeka mix, small brick cubes, etc. We have successfully utilized this method in reducing high surface maintenance costs where the macadam foundation was solid enough for the traffic, and have adopted this method for a number of our roads. We have examples which have stood a 10 years' test successfully.

"We believe that the community has been better served by constructing 10 miles of macadam in place of a possible 6 miles of rigid pavement.

"We believe that the county has been better served in the past and will be best served in the future by variable road designs using for the majority of the mileage modern macadam for the original construction, later modified, if necessary, for a very limited mileage by recapping with a lower maintenance cost surface. We advocate rigid pavements eventually for, approximately, 10 per cent. of the total mileage of our roads and for approximately 35 per cent. of our State System."

The fifth principle of design becomes: Vary the type of pavement to suit the demands of existing traffic. Avoid the use of rigid pavements on local service roads except for unusual conditions of material supply.

Pavement Width.—The number and width of vehicles using the road controls the design of pavement width and in many cases the type of pavement surface. It is, however, well to bear in mind that, in order not to violate the first principle of design, namely, *Mileage Service*, the basis for the selection of width should be the expected volume of traffic in the immediate future and not the far distant future. It is always possible to widen or improve the pavement under a Maintenance or Reconstruction program. *The sixth rule of design may be stated as: the number of vehicles and the percentage of horse traffic govern the width of the pavement and its surfacing.* The practical application of this rule may be indicated in a rough general way as follows:

Single track pavements 8 to 12 ft. wide built of good natural soil materials, gravel or macadam serve very satisfactorily if properly maintained under a local service traffic up to about 300 vehicles per day in the busy season. In well settled communities a road of this kind is generally a cross road.

Double track pavements 15 to 16 ft. wide built of thick modern waterbound or bituminous macadam with special shoulders if necessary will serve satisfactorily up to approximately 1800 local service vehicles per ten-hour day in the busy season if

properly maintained. In well settled communities a road of this class is generally a secondary radial road or it may constitute the least used portion of a main road connecting large cities located more than 100 miles apart.

If traffic exceeds this amount macadam maintenance generally results in too much interference with traffic even if the vehicles are light units although there have been cases of the successful use of penetration bituminous macadam up to 3500 vehicles per day, 300 of which were trucks. As a rule a volume of traffic of over 1800 rigs per ten-hour day in the busy season means that

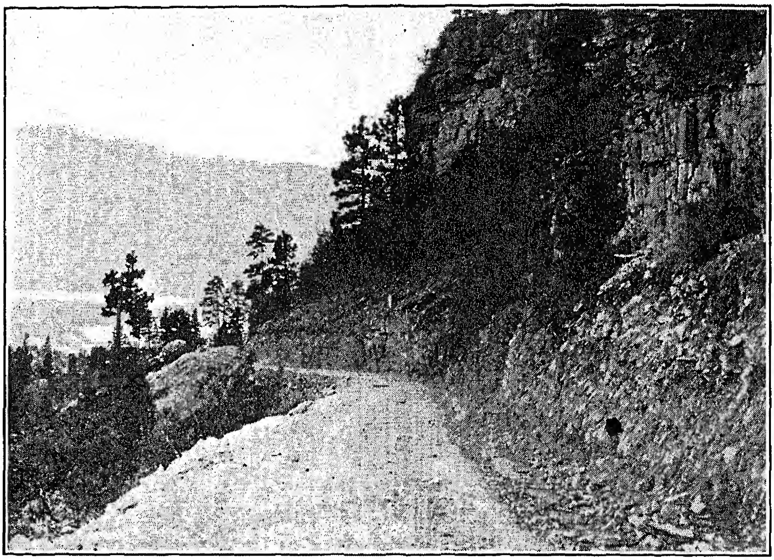


FIG. 8.—Typical unprotected mountain road. Illustrates the necessity for careful driving. Continuous guard rail would be prohibitive in cost except on a few of the main transcontinental routes.

the road should be classed as a special service road entitled to a high cost rigid pavement. Roads of this class are generally main roads between large cities located less than 100 miles apart or main Radial Roads for a distance of 5 to 40 miles from cities or special Industrial Roads. Rigid pavements less than 18 ft. wide are rarely satisfactory to traffic on account of the formation of ruts in the shoulders along the edge of the pavement. Present sentiment favors 20-ft. width of rigid pavements on main roads near cities. In very unusual cases a pavement width of 29 or 38 ft. is desirable.

The relative mileage of single and double track pavements will, of course, vary for each locality but it is not likely that even in the more populous states that more than 10 to 20 per cent. of the roads need to be designed as double track roads and it is not probable that at the present time over 1 to 5 per cent. can be classed as special service roads.

Safety and Convenience of Traffic.—The amount of money that it is desirable to spend on safeguards to traffic is largely controlled by the volume of traffic. Extreme danger should be avoided on any improved road but on the lighter travelled roads considerable must be left to the care of the driver. On such roads about all that is justified are danger signs and cheap guard rail that warn instead of actually protecting and on many mountain roads even cheap guard rail is out of the question (see Fig. 8). On heavy travel special service roads all possible safeguards should be employed, such as the elimination of railroad grade crossings, substantial strong concrete guard rail or retaining walls, widening and banking the pavement on curves, a safe "sight distance" ahead at all times, shallow ditches, and warning and guide signs for the direction of travel. *The seventh rule of design covers safety of traffic. On light traffic roads confine safety provisions to warnings. On heavy traffic routes spend all the money that is necessary to make the road as nearly fool proof as possible.*

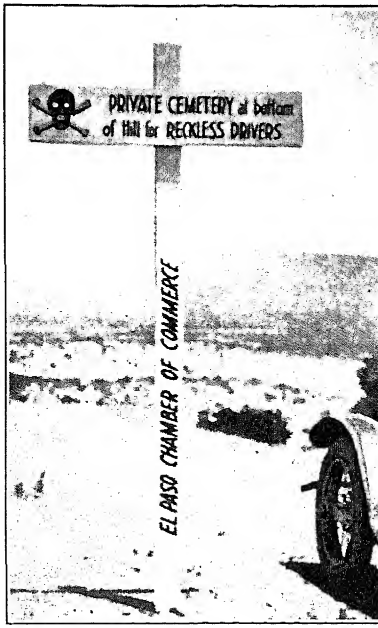


FIG. 9.—An unusual and effective warning sign on an unprotected road.

Materials and Their Effect on the Selection of Pavement Type.—The proper use of available local road building material is a fundamental economic principle in road design and properly controls the selection of pavement type. This principle is rarely disregarded in small local programs where the funds are

limited and the officials are in close contact with the taxpayer, or in State aid Work in the sparsely settled States where the funds are small. Unfortunately its violation is quite frequent in State Aid Work in the rich States committed to very high class pavement design and is probably due to the tendency of large state organizations to generalize too broadly both on the minimum acceptable requirements of materials and on the selection of pavement type. That is, they often fail to analyze each job carefully, to make comparative estimates of cost and to modify a general specification to make it adaptable to special conditions. They are working with large appropriations and have not much personal incentive for clean cut efficiency. The proverbial drunken sailor is sometimes a piker in comparison. I do not mean by this that the roads are not well constructed for as a rule the construction is A number one and is in fact much better than that obtained under local control but the amount of money spent in the process is often needlessly high. It is well worth while to make a systematic effort to stop all the small leaks which amount to large figures in the aggregate. This does not mean that local control of Highway Design is better than State or National Control. We have had enough experience with both methods to demonstrate the very marked advantage of State and Federal Control in improving the general character of programs but this particular weakness can and ought to be corrected.

The desirability of the proper use of local material does not seem open to argument and the *eighth rule of design becomes: inferior material should never be used, but the type of pavement should be varied to permit the proper use of existing local materials or the cheapest imported materials.* In practice this requires very thorough investigation of all local supplies. It necessitates a common sense attitude of the testing laboratory; it requires a reasonably flexible specification but it results in saving more money than any other single detail of design. The requirements of materials are discussed in the second book of this series, but to illustrate the practical application of this principle in a general way a couple of possible cases will be outlined.

Suppose a local service road carrying approximately 400 vehicles per day is to be built. That a limited supply of coarse gravel is available fit for bottom course macadam construction but not fit for concrete pavement or concrete paving base. That there is enough of this gravel to build a satisfactory bottom course for

1 mile of road with a short haul. Suppose at the other end of the road there is a local quarry of stone fit for bottom course but not hard enough for macadam top or concrete pavement. Under such conditions comparative estimates of original construction cost, maintenance and renewal for the different possible types will generally show a distinct saving in both first cost and ultimate cost for a macadam road utilizing the local gravel for 1 mile of bottom, the local stone for 3 miles of bottom and a hard imported stone top. Under these conditions the author has seen time and again either the entire elimination of the gravel if macadam is used or entire elimination of local materials by the adoption of concrete pavement for the full distance. It is against this tendency that we wish to throw the weight of existing evidence.

Suppose a local service road handling approximately 1500 vehicles per day is to be built and that a first class local stone is available fit for any grade of macadam or concrete but that concrete pavement sand has to be imported. Suppose that comparative estimates of construction cost show that an 18 ft. concrete pavement will cost only $8,000 per mile more than a satisfactory 16 ft. Bituminous Macadam with special macadam shoulders, and that there are enough funds available to construct the entire length of the proposed improvement with concrete. Under these conditions considering the factors of life, maintenance and renewal it is probably desirable to select the concrete pavement. If the difference in cost had been say $9,000 per mile for price conditions prevailing in the year 1920 it is probable that the selection of Bituminous Macadam would be the proper solution The deciding point in comparative costs of different constructions will vary for different localities, different traffic and different years as discussed later but some such basis of selection must be borne continually in mind if you expect to give a rational explanation of the selection of type. Each road must be analyzed on this basis as it often happens that within a couple of miles of each other, two different roads will require entirely different conclusions. There is too much generalization in type selection. Time after time the author has been forced to build inadequate macadam roads because there happened to be a reaction against high grade pavements that particular year. This is as shortsighted as the opposite tendency noted above. The actual working out of highway programs is rarely logical as there are too many conflicting interests to be considered but wherever it is possible to do

so a reasonable analysis should be given the selection of type. Type selection is also often befogged by various arguments connected with the method of financing the improvement.

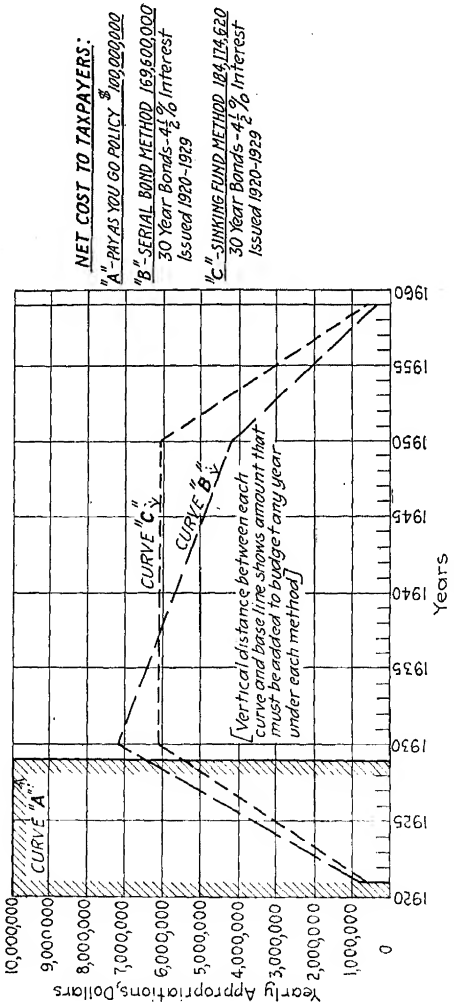


CHART A.—Graphic comparison of three methods of financing. (Total and yearly costs.) 10-year construction program.

Financing Improvements (Effect on Design).—Reasonable finance programs are based on the relative cost and length of life of the temporary and permanent features of road construction.

Improvements are as a rule financed in one of three ways:

1. "Pay as you go" policy.

2. Serial bonds whose terms are based on the life of the improvement.

3. Long term bonds (sinking fund method).

The comparative total cost to the taxpayers of these methods is illustrated by Charts A and B. The "Pay as you go" policy is, of course, the least expensive in total cost but has a number of drawbacks The serial bond method is in more favor at present than either the first or third method. The total cost to the taxpayer increases with the length of the bond term

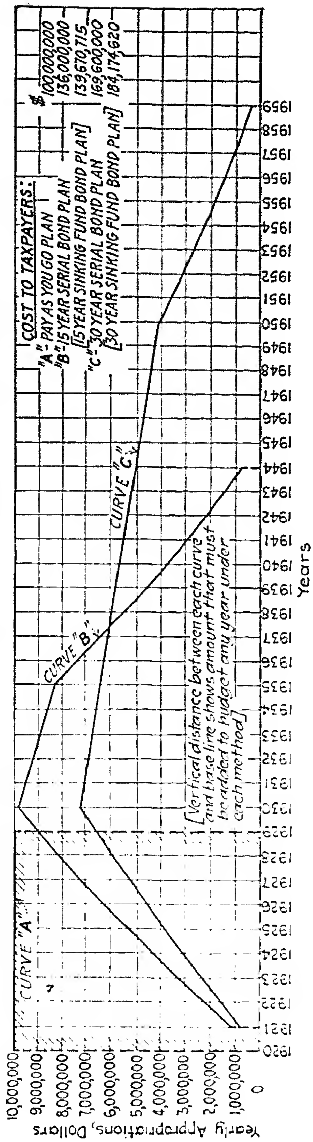


CHART B.—Graphic comparison of the effect of length of bond term on total and yearly cost. 10-year construction program.

Long term bonds have been used in the past as they provided a more or less painless method of extracting the necessary money but the additional total cost of a fifty year term bond, which has often been used, and its evident fault of throwing too much of the burden on the future has resulted in practically eliminating such a long term method. Bond issues of some sort for the original construction of a highway system have the advantages of making it possible to carry out a co-ordinated scheme more easily than the "Pay as you go" policy. They make it easier to get a continuous program of construction and to organize and operate a reasonably effective engineering organization for the design and construction. The serial bond method based on a twenty-five or thirty year term and financed by general tax levy seems reasonable for the original construction

of a general system of highways composed of all the different types of pavement that would ordinarily be used to serve the average road user. The "Pay as you go" policy or serial bonds of about a fifteen year term financed by auto licenses or some other form of direct vehicle tax seem reasonable for a Reconstruction Program of boulevards or special Commercial Roads. It is self evident that maintenance funds should be "*Pay as you go*" and probably financed by direct vehicle taxes.

The methods of raising road funds vary for the different States and are changed from year to year. The Highway Green Book issued yearly by the American Auto Assoc. affords a convenient reference for up to date data on road laws and methods of raising funds. Appendix A reprints their discussion of Highway Bonds.

Reasonable bond terms are based on the following general data. On well built roads the pavement surfacing or resurfacing and other minor elements such as gutters, guide signs, etc. are the temporary features. The other items of work such as grading, well built culverts, and foundations are relatively permanent. The top course of double track macadam type roads use up as a rule from 40 to 50 per cent. of the total cost of original construction and last from 8 to 12 years on local service roads before a new top course is necessary. That is, the deterioration of macadam roads can be assumed to be 40 per cent. in ten years and after that time there is very little further deterioration of the original construction. The resurfacing of rigid type of pavement can be assumed to cost about 60 per cent. of the total original cost of the road and resurfacing is generally required in from 15 to 20 years. The deterioration for such roads can be assumed roughly as 60 per cent. in 15 years after which there is very little further depreciation on the original investment.

Any scheme of financing which pays off 40 per cent. of the original loan in 10 years and 60 per cent. in 15 years appears reasonable for any general improvement program covering roads of different types. The twenty five year serial bond accomplishes this making it possible to reconstruct these pavement surfacings at the proper time without pyramiding loans. For reconstruction programs, however, the term should not exceed 15 years as the total expenditure is on temporary features.

Programs based on 50 year bond issues can not by any expedient of the engineer be made reasonable from the standpoint

of the relation of the life of the surfacing to the term of the bond but this fact should not influence the engineer in his choice of pavement type if he has to work under such a bond issue. The following attitude has had considerable publicity. "If our bonds are 50 year bonds, build our roads to last for 50 years. Build Permanent Pavements. Build Concrete or Brick or Sheet Asphalt (depending on the business connections of the speaker)." As a matter of fact no large mileage of concrete will last for 50 years without resurfacing, neither will brick, neither will sheet asphalt, neither will macadam. As a matter of fact, the only road that does not need resurfacing in 50 years is a natural earth road.

Why therefore cut down needed mileage and reduce *mileage service, the first principle of design,* by the use of rigid pavements on side roads where there is no engineering justification for them. A well designed macadam road under traffic for which it is suited will not cost any more for 50 years including maintenance, renewals, and interest on first cost than a rigid pavement on the same road. A long bond term never justified the use of rigid pavements on local service roads and the *ninth rule of design becomes: Every effort should be made to obtain a reasonable term of bond but if a long term is used, do not permit the term of bond issue under which the improvement is made to influence the selection of pavement type.*

Contract Relations.—Assuming that the road is well designed it is necessary to get it well built. Sound business relations between contractors and the directing engineering organizations is manifestly the only possible means of getting good work at a reasonable cost. Any element of unnecessary risk or uncertainty which the contractor must assume raises the bid price of the work. Any doubt as to whether the work will be let provided a reasonable bid is secured tends to keep away responsible contractors. Prompt decision and uniform treatment are essential. Reasonable profits are necessary to insure good work, for the community usually gets just what it pays for.

The author has heard public officials say that they figured to catch a sucker at every letting. They often did, but the result was that they either got a rotten job or had the difficulty of finishing the work themselves with all the usual complications. Fortunately this attitude has few supporters today and it may be stated as a general principle that *uncertainty must be eliminated*

as far as possible, reasonable prices must be paid and the size of contracts should be varied in order to interest organizations that can best handle the road in question.

The uniform use of long mileage contracts is no more desirable than the use of short contracts. Large organizations have a high overhead and equipment charge and there are generally not enough of them to insure lively competition. They can afford to provide labor saving machinery which is a distinct advantage during times of labor shortage. The award of long contracts to large organizations is probably desirable for high priced rigid pavements, *particularly in sparsely settled communities.*

Short contracts tend to encourage competition. They can generally be finished in one working season which eliminates considerable uncertainty in the labor situation and the cost of materials. They can generally be handled with local labor, particularly in well settled districts; they cause less inconvenience to the travelling public during construction. They are probably desirable for the construction of roads in well settled districts, particularly where the macadam form of pavement is used.

Uncertainty in bids can be reduced by complete and definite plans and specifications that have the reputation of being enforced. By definite statements of the requirements of materials and the location of acceptable supplies of these materials. By the publication of the engineer's estimate of cost with a statement as to the maximum bid that will be considered in awarding the contract and by the provision that in case a responsible contractor makes the low bid under the limit stated and no award is made that he will receive a reasonable fee for making the bid.

To determine reasonable prices every large state organization can afford to develop a construction department which can do certain jobs each year to gauge reasonable construction costs and to take over for completion any contracts that may be cancelled for non performance.

Maintenance.—The final cost and length of life of pavement surfaces depend on the efficiency of maintenance. Maintenance is the most disagreeable feature of road programs. It is well to remember that the only permanent feature of road work is *Repair* and that no pavement will last long no matter what its original cost. Maintenance is something that we have always with us, that is the fly in the ointment, that makes the Highway Commissioner grayheaded if he is inclined to worry

and that in many cases has not been handled with much foresight by the legislative bodies responsible for maintenance appropriations.

Efficient maintenance can only be accomplished by preventing damage instead of repairing damage and it is very difficult to persuade a non technical legislative body that large sums of money are necessary for this work before they have some physical evidence of the necessity. Such evidence is only supplied by a road that has been allowed to go to pieces and that the public is complaining about. This involves reconstruction which is not properly classed as maintenance and is much more expensive than preventive measures.

Maintenance policy is an excellent example of the fact that the future has a habit of taking care of itself. In the author's home state, New York, no adequate maintenance policy was adopted at the start of State aid road construction. In a short time the necessities of the situation gave the necessary impetus for some improvement in maintenance work and this improvement has been steady. In the last eight years (1913–1920) the organization has reached a stage where it has demonstrated its ability to handle all kinds of pavement repair with moderately good results provided the necessary yearly appropriations are made. Such appropriations are not yet up to the requirements of really farsighted efficient maintenance but we hope it is only a question of time until this is also accomplished. This gradual development of efficiency is very typical of the average community. *Reasonably effective maintenance has been accomplished and can be accomplished* in spite of the practical difficulties of the job.

The comparative cost of flexible and rigid pavement maintenance will be discussed in detail in the second book of this series but at this point it is sufficient to note that under poor maintenance flexible gravel or macadam construction is worthless; that under moderately effective maintenance they compare favorably with rigid pavements in ultimate cost on local service roads where all classes of road material are locally available and that under really good maintenance macadam has a distinct advantage over rigid pavements up to about 1800 vehicles per ten hour day in the busy season. It is well not to permit the fear of inadequate maintenance in the immediate future to influence the selection of pavement type.

The fact that maintenance has been poorly handled in some cases, resulting in a short life of the macadam pavements has led a number of Engineers to dodge the difficulty by building rigid pavements. As a matter of fact the slogan of the concrete men, the brick men, etc., "*Build the maintenance into the road*" has considerable merit provided we admit that the American Public Official can not handle maintenance.

The man in charge of maintenance has a hard job. His work is not spectacular. If he keeps the roads in excellent condition it is taken as a matter of course. If the roads are not kept in good shape very little charity is extended in his direction even though he has been handicapped by a shortage of funds. Legislators as a rule do not appreciate the large amount of money required and apparently take delight in cutting the estimates where they would not think of tampering with construction appropriations. Maintenance is a convenient way of dispensing minor patronage, etc., but good work has been done and can be done and if the community ever expects to complete a general system of roads it must be done.

There is one thing certain, the policy of "*building the maintenance into the road*" by the use of a short mileage of extremely high priced pavements on account of the fear that it will be impossible to maintain a less expensive type violates the first principle of *Mileage Service*. It also often puts the hidden burden of maintenance on the community at large as part of the original construction cost instead of on the road user as a yearly charge. This last contingency has been avoided in some cases by financing original construction with auto license fees but the wisdom of this method is open to argument where this robs needed maintenance funds and the short mileage result can not be overcome. Needlessly short mileage is the most serious criticism that can be made of any general policy dealing with an incomplete Road System.

The last principle of design becomes: *efficient maintenance is essential. The lack of a well defined maintenance policy should be remedied by making the maintenance effective and not by sidestepping the issue with a needlessly short mileage of high first cost, low maintenance cost pavements.*

Summary of General Principles.—The foregoing principles may be summarized as follows:

First.—The construction of the greatest possible mileage of connected roads of a type suitable to the stage of development of the community and its existing traffic. Mileage is the first and foremost factor of service.

Second.—Traffic must be regulated not only to save past investment but also to enable the community to finance any enduring general system of roads and to make economic engineering design possible.

Third.—Local traffic is entitled to first consideration in the location of roads and their design except for a comparatively small mileage of special service roads.

Fourth.—The maximum regulated load for the class of service for which the road is intended should govern the strength of the pavement foundation and bridges and no attempt should be made to reduce construction cost by using weak foundations. Heavy traffic must be ruled off from local service roads.

Fifth.—The varying demands of traffic require variations in pavement type. As a general rule avoid the use of rigid pavements on local service roads except for unusual conditions of material supply.

Sixth.—The number of vehicles and the percentage of horse traffic using the road govern the width of pavement and its surfacing.

Seventh.—Volume of traffic controls the designs of safeguards. On light traffic roads confine safeguards to warnings. On heavy traffic roads make the road as near fool proof as possible.

Eighth.—Inferior material should never be used but the type of pavement should be varied to permit the proper use of existing local materials or the cheapest imported materials.

Ninth.—Every effort should be made to obtain a reasonable term of bond but if a long term bond has been adopted do not permit the term of bond issue under which the improvement is made to influence the selection of pavement type.

Tenth.—Uncertainty must be eliminated as far as possible in contract relations, reasonable prices must be paid to insure good work and the size of the contract should be varied in order to interest organizations that are best fitted to handle the roads in question.

Eleventh.—Efficient maintenance is essential. The lack of a well defined maintenance policy should be remedied by making the maintenance effective and not by sidestepping the issue with a needlessly short mileage of high first cost, low maintenance cost pavements.

Conclusion.—These principles will serve as a basis for the development of detail design practice. While they may not apply to all cases, some such general scheme that will fit the requirements of the locality in question is a necessary step in any reasonable scheme of design and construction. They serve as a fixed goal to aim at and are very useful as a guide when the Engineer is floundering in detail or badly hemmed in by circumstances.

CHAPTER II

PROPORTION AND ECONOMY IN DESIGN

The Relative Importance of the Detail Elements of Design.—Most roadwork can be classed as a step in progressive improvement; the highway is gradually bettered from a trail to a high-class, modern, heavy-traffic thoroughfare as its use or prospective use warrants the expenditure. In the majority of cases the money at hand is not sufficient for the complete construction of

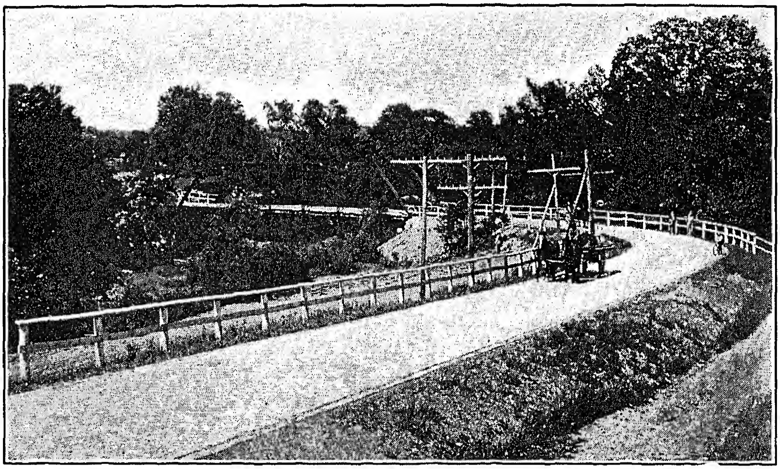


FIG. 10.—Expensive rigid pavement highway with dangerous alignment, dangerous section, flimsy guard rail and weak bridging.

all the features that are desirable even at the time when the improvement is made, and it is never sufficient to build a road that will completely fill the requirements of the future. Some features have to be omitted or slighted. It therefore seems well worth while to encourage first the construction of reasonably good fundamental elements which act as a basis for the final improvement, and then in logical order as many of the other desirable parts as can be built.

Where the funds are inadequate for a completely satisfactory design the results often show a lack of proportion. Figure 10

will perhaps show in a general way the point I have in mind. It shows a high-class pavement with dangerous alignment, dangerous section, flimsy guard rail and weak bridging.

It certainly pays to construct what is done so that it can be readily strengthened and widened as the future requires, without losing the benefit of previous work. The following tentative list illustrates an order of importance of design elements which probably applies to most cases, with some minor variations:

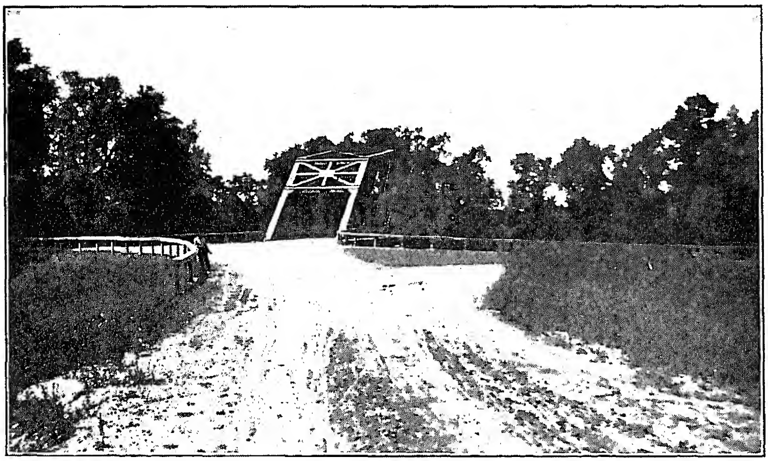


FIG. 11.—Substantial modern bridge with well designed approach protected with concrete guard rail.

DESIGN FEATURES

First, selection of the best general route.

(*a*) Best location for the development of the territory.
(*b*) Longest open season.
(*c*) Least rise and fall.
(*d*) Length and cost.

Second, selection of the most natural engineering location following the desired general route

(*a*) Reasonable grades.
(*b*) Exposure. Avoid north exposure and areas of deep snow.
(*c*) Character of excavation. Avoid rock, slides, etc.
(*d*) Drainage problems. Avoid flood areas, stream crossings, etc.
(*e*) Avoid artificial restrictions such as section line locations, etc.

Third, detail requirements of design.

(*a*) Reasonable maximum grade, considering future requirements.
(*b*) Economical intermediate grades.

(*c*) Safe and economical alignment, considering future requirements.
(*d*) Width of roadway safe for traffic, eliminating dangerous ditches.
(*e*) Width of roadway convenient for traffic.
(*f*) Sufficient culverts and bridges to protect the roadway, considering the future.
(*g*) Permanent construction of these culverts and bridges.
(*h*) Sufficient width of clearing for sun to reach road.
(*i*) Safety provisions. Protection for traffic at dangerous places.
(*j*) Provision of liberal width of right-of-way, considering future widenings and development.

Fourth, improvement of the road surface.
(*a*) By selective soil treatment.
(*b*) By gravel, chert, macadam, etc.
(*c*) By rigid pavements.

Fifth, improvements for the future.
(*a*) A higher-grade surface.
(*b*) A wider hard surface.
(*c*) Provision of sidewalks for pedestrians.
(*d*) Planting trees, etc.

An examination of the roads in almost any locality leaves the impression that a little more emphasis on and attention to the better construction of the fundamental features will add to the reasonable proportion of design and be a move in the right direction.

The following typical cases illustrate the usual problems that occur and indicate their general solution.

General Solutions Pioneer Districts.—Where no road exists and the funds are entirely too small for good construction, a sufficiently cheap design is used to complete the entire length. Under these conditions the only requirement that must be met is the proper selection of general route, although it is probable that for the greater part of the distance the final engineering location can be followed. Considerable work of this kind has been done in the southwestern states, and the solutions are ingenious. Satisfactory wagon and automobile trails have been constructed under favorable conditions for as low as $20.00 per mile, while in difficult locations advantage has been taken of all possible expedients to keep the cost down.

Where a poor but usable road exists between the terminal points, or for a portion of the distance, either the uncompleted or worst sections of the route are first considered. Under such circumstances the funds are generally sufficient to permit a moderately good engineering design, which must prvoide for a reasonably good grade and drainage scheme on the improved

sections, although the drainage structures may be cheap and temporary and the roadway narrow.

Where a fair road has been previously built over the entire route, no improvement should be attempted unless it provides for a first class engineering design of grades, alignment, section and permanent drainage structures.

Where a first-class natural soil road is in use the next step in progressive improvement requires either selected soil, gravel or hard surfaced construction of the traveled way.

General Solutions Well Settled Districts.—The application of the order of importance of design elements for hard surfaced pavement work can be shown by three cases:

Under the most favorable conditions in rich communities, the improvement is considered final and its design is based on an effort to obtain the most useful, and in the end the most economical form of construction regardless of first cost. In this case all the engineering requirements may be fulfilled.

In many communities, however, the funds are only sufficient to build a moderately good pavement, which will have to be bettered by reconstruction in a few years, to meet the increasing demands of the traffic. An improvement of this kind should be permanently and completely designed for proper grades, alignment, section, drainage and safety provisions, up to a certain reasonable limit and the balance of the money spent on the best type of hard surface that can be afforded.

The third case is reconstruction, which usually confines the problem to consideration of the most suitable type of resurfacing, utilizing previous work to the best advantage. It also sometimes involves improved relocation.

Reasonable Economy in Design.—The mileage to be constructed is so great (see Table I) and the amount of money involved so impressive that it seems desirable to use all reasonable care to produce as many miles of road as possible with the available funds. During the years 1913–1920 the author has made a careful review of some 2000 miles of road plans from different sections of the country with the idea of forming a reasonable conclusion as to the trend of highway design and to see how closely current practice follows the well recognized principles of highway engineering. The results of the analysis of these plans were, roughly, as follows: About 25 per cent. could be classed as first-class designs from an economical standpoint. Practically all

..OAD MILEAGE IN THE UNITED STATES IN 1914. (Bulletin U. S. Public Roads)

State	Total road mileage	Miles surfaced	Percentage surfaced	Total mileage: Per sq. mile of area	Total mileage: Per 1000 rural population	Surfaced mileage: Per sq. mile of area	Surfaced mileage: Per 1000 rural population
Alabama	55,446	4,988	8.99	1.08	31.3	0.097	2.82
Arizona	12,075	253	2.09	0.11	85.5	0.002	1.79
Arkansas	50,743	1,097	2.16	0.96	36.9	0.020	0.80
California	61,039	10,279	16.84	0.39	67.2	0.066	11.32
Colorado	39,780	1,193	3.00	0.38	100.9	0.011	3.02
Connecticut	14,061	2,975	21.16	2.92	122.3	0.617	25.89
Delaware	3,674	243	6.62	1.86	34.9	1.240	2.32
Florida	17,995	2,830	15.72	0.33	33.6	0.052	5.29
Georgia	80,669	12,342	15.30	1.37	38.9	0.210	5.96
Idaho	24,396	679	2.78	0.29	95.4	0.008	2.65
Illinois	95,647	11,606	12.02	1.71	44.2	0.207	5.37
Indiana	73,347	30,962	42.20	2.03	47.1	0.858	19.88
Iowa	104,074	614	0.59	1.87	67.3	0.001	0.39
Kansas	111,052	1,148	1.03	1.35	92.7	0.014	0.96
Kentucky	57,916	12,403	21.40	1.44	33.4	0.308	7.15
Louisiana	24,563	2,067	8.42	0.54	21.1	0.050	1.78
Maine	23,537	2,762	11.74	0.79	65.3	0.092	7.65
Maryland	16,459	2,489	15.10	1.65	25.8	0.250	3.90
Massachusetts	18,681	8,505	45.53	2.32	77.5	1.058	35.29
Michigan	74,190	7,828	10.55	1.29	50.0	0.136	5.28
Minnesota	93,517	3,967	4.24	1.15	76.3	0.036	2.42
Mississippi	45,779	2,133	4.66	0.98	28.8	0.046	1.34
Missouri	96,041	6,712	6.98	1.39	50.6	0.097	3.54
Montana	39,204	609	1.55	0.27	161.5	0.004	2.51
Nebraska	80,272	1,204	1.50	1.04	91.0	0.001	1.36
Nevada	12,182	262	2.14	0.11	177.8	0.002	3.82
New Hampshire	14,020	1,659	11.83	1.55	79.9	0.184	9.47
New Jersey	14,817	5,897	39.80	1.97	23.5	0.784	9.40
New Mexico	11,873	261	2.20	0.09	42.3	0.002	0.93
New York	79,398	15,635	19.60	1.66	41.2	0.328	8.10
North Carolina	50,758	6,003	11.82	1.04	26.8	0.123	3.18
North Dakota	68,796	955	1.38	0.98	138.8	0.013	1.86
Ohio	86,354	30,569	35.16	2.12	41.0	0.750	14.54
Oklahoma	107,916	121	0.11	1.55	80.7	0.002	0.09
Oregon	36,819	4,726	12.83	0.38	100.6	0.049	12.89
Pennsylvania	91,555	9,982	10.90	2.22	30.2	0.220	3.29
Rhode Island	2,170	693	31.95	2.03	120.8	0.649	38.59
South Carolina	42,226	3,270	7.74	1.38	32.7	0.107	2.53
South Dakota	96,306	363	0.37	1.25	189.8	0.004	0.72
Tennessee	46,050	8,102	17.59	1.10	26.4	0.194	4.64
Texas	128,960	10,526	8.16	0.49	43.6	0.401	3.56
Utah	8,810	1,153	13.09	0.11	43.9	0.014	5.76
Vermont	14,249	1,442	10.12	1.56	76.2	0.158	7.71
Virginia	53,388	3,909	7.32	1.32	33.7	0.097	2.46
Washington	42,428	4,922	11.61	0.63	79.0	0.073	9.17
West Virginia	32,024	1,064	3.30	1.33	32.3	0.044	1.07
Wisconsin	75,707	13,399	17.60	1.37	56.9	0.242	10.08
Wyoming	14,797	468	3.10	0.15	147.9	0.005	4.56
United States	2,445,760	257,291	10.52	0.82	49.5	0.086	5.21

the designs showed minor wastes, but for the plans classed as good, revisions would not result in any practical advantage. About 75 per cent. of the plans showed a material expenditure of money for which no adequate return was obtained, amounting to from 5 to 20 per cent. of the cost. On some of the roads which, as built, served the traffic well, this excess might better have been spent on other jobs. On some of the roads which, as built, were

not up to the requirements of the traffic, the waste might better have been applied to their own improvement in fundamental features.

The general faults most noticeable were:

Too much spent on the reduction of intermediate grades.
Too much spent to obtain long straight grades.
Too much spent on sections with deep ditches.
Not enough spent on realignment at dangerous locations.
Not enough spent on relocations necessary to get reasonable maximum grades.
Not enough spent on long-span bridges.
Too much spent on width of macadam.
Not enough spent on depth of macadam.
Too much spent on imported materials where local materials were available in limited quantities.

One of the objects of these books is to discuss in detail various proved means of effecting economies without reducing the usefulness of the roads. At this point, however, it is not necessary to more than indicate the different parts of design that are particularly susceptible to such saving.

Systematic grading design will often reduce the work from 500 to 2500 yd. per mile, amounting in money, on an average, to from \$500 to \$1000 per mile. The proper use of local material particularly in foundations is a large factor in economy and will often reduce the cost from \$1000 to \$3000 per mile. Reasonable variations in pavement width and in the thickness of surfacing courses is effective and in many cases saves from \$1000 to \$2000 per mile. A very conservative estimate of savings due to these systematic minor alterations is from \$1000 to \$2000 per mile. These savings are not spectacular for any one job but if consistently used their advantage on any large program is very evident. They will more than pay for all the necessary engineering work in connection with the entire program. The small additional work required for a careful analysis is the best posible engineering investment for the community that can be made.

Tests of Designs.—It is certainly well worth while to test out each finished design to see if it complies with the general principles which have been discussed and also with the detail economies that will be taken up later. The following list of questions indicate in a general way the points to be considered:

Questionnaire

Is the alignment suitable for all reasonable requirements of the future?

Is the ruling grade suitable for all reasonable requirements of the future?

Is the section, ditch to ditch, safe and suitable for present traffic?

Is the right-of-way wide enough for future requirements?

Are there ample culverts for all requirements of the future?

Are the culverts proportioned properly as to size considering run-off?

Are the culverts long enough to be safe and large enough to maintain?

Are the bridge superstructures strong enough for present traffic?

Have all permanent culverts and bridges been designed strong enough and wide enough for, say, 50 years?

Are the bridge abutments for new temporary superstructures solid enough for future permanent superstructures?

Are the ditches road ditches and not farm drainage ditches?

Are the safety provisions real safeguards or are they only warnings?

Is the road surface thick enough to handle present traffic without foundation failure, considering the subsoil conditions?

Is the road surface wide enough for present traffic?

Is the surface of the general type required by present traffic?

So much for Proportion—now for Economy:

Does the grade line conform with the principles of economical design?

Do the sections fluctuate to conform to economical design?

Has the selection of pavement type been based on the most economical use of local materials?

Has the design been varied to use limited supplies of local material with short hauls?

Is the width reasonable, and has it been varied on a road that has heavy traffic part of the distance and light traffic part of the way?

Has the depth of macadam been varied to meet the different requirements of the soils and kept to a reasonable minimum?

Have the culverts and bridges been designed for the most economical type for the span in question?

Have the types of culverts been varied to get the cheapest result, considering local materials, in comparison with market quotations and cost of long hauls on imported materials?

Are the specifications flexible enough to permit the reasonable use of local material?

Does the testing laboratory make an effort to approve the reasonable use of local material, or is it inclined to hold arbitrarily to the highest standards, regardless of the relative importance of the job in hand?

The designer should, however, bear in mind that imperfections in construction and indeterminate factors make too close a theoretical design impracticable and that a certain factor of safety must be provided in all his plans for such possibilities. The application of this to the different elements of design will be discussed throughout the books.

Order of Work.—The detail methods employed in the field and office work are described in the third book of this series. In pioneer districts the general order of work is as follows:

A preliminary investigation is made to determine the general route, the best engineering location and the approximate cost of construction. It forms the basis for the general scheme of financing and design. It is the most important feature of new road location, and if well done insures the completion of a reasonable program of construction with the funds at hand. It also prevents wasteful expenditure on ill considered or unsuitable location surveys and plans. The detail location survey based on the preliminary conclusions is next made to secure the data for the final office design, which carries out in detail the recommendations of the first report and completes the work preliminary to construction.

In well settled communities the order of work is the same. The character of the information for the preliminary investigation is different, but the object is identical; namely, to provide a basis for appropriations and reasonable design. The preliminary data deals largely with probable traffic, available local materials and the most suitable and economical pavement type. The location survey provides the essential data for design, using somewhat better methods than for mountains conditions, and the office work is more detailed and complete.

Conclusion of Chapter.—During the last ten years, road design has been improved by standardization. This is a necessary step in the development of efficient organizations but it is only a preliminary step which has already been carried up to or beyond its desirable limit in many states. The more or less prevalent stereotyped use of Standards not only results in a needless expenditure of public funds for construction but tends to discourage independent thinking by the rank and file of the force. Standards serve their purpose by providing a minimum standard of excellence and by saving time and duplication of effort in designing ordinary structures; that is about their limit of usefulness. Further improvement in general highway practice lies very largely in an educational policy along the lines of systematic economical design and the use of engineering judgment in the application of standards.

The natural tendency of the man new to roadwork is to copy existing local practice with very little thought as to its reasonable

application. If designers will think for themselves a long step forward is accomplished. They are not so apt to be stampeded by trade propaganda or to develop a habit of mental laziness that is willing to accept any method that will, to use a slang phrase, *"Get by."* Any technical analysis is of value only when its application is based on common sense. It is very evident that any system of design which does not take advantage of and encourage the initiative of the intelligent and experienced men on the force is radically wrong. It is probably true that a few of the usual Civil Service Engineers and Inspectors are not active mentally. For this class of men an effective way to encourage reasonable design and force the designer to make an analysis which he can defend is by *"Check Lists."* This method is illustrated in detail in the third book of this series. However, it is just as well to emphasize the fact that there is a genuine personal enjoyment in a complete, reasonable, economic analysis of road design. A great many young men have said that it took them a long time to realize this and that they were as a rule indebted to some older Engineer for the point of view. I have seen the radically different results obtained by these men after they had developed the habit of analysis and it is hoped that the economic advantages of careful engineering can be effectively shown throughout the books and particularly in Volume III by examples of actual design worked out in the usual standard manner and then modified by systematic criticism.

The success of any program depends very largely on the personnel of the directing organization. The national tendency of making public work the football of partisan politics may add interest to life but it certainly does not add efficiency to a road program. It is often extremely difficult to carry out any well balanced plan. We generally get the roads somehow and some way but main strength and awkwardness play a large part in the game. It is well to bear in mind that while present procedure can undoubtedly be improved that the net result of Highway programs to date has been excellent and the communities have received entirely satisfactory returns on their investment in improved roads. State and Federal control has radically improved engineering design and methods of financing. It has eliminated most of the petty local interference with sound design but the danger to guard against from centralizing the authority lies in too much generalization, lack of flexibility and the beaurocratic

attitude which tends to smother the development of the promising younger men. Any method which tends to stabilize general policy or improves the character of the engineering organization is a move in the right direction. Careful layouts and complete classifications which are well made and well advertised have some effect in preventing radical changes by successive administrations. These expedients are discussed in the next chapter.

CHAPTER III

CLASSIFICATION, ROUTE AND GENERAL ENGINEERING LOCATION

Road Systems.—The first step of road improvement programs is to plan the system and classify the roads. A general layout is necessary to insure a well connected and serviceable system for both local and long distance traffic. A great deal of thought has been given to the layout of state and county highways and the general plans are fairly well fixed in most localities. Comparatively few engineers will have the opportunity to assist in planning large systems but it will do no harm to give a short discussion of the general principles governing layout, classification and the selection of route.

Layout of Systems.—Layouts are based on the part that the highways play in the general transportation scheme for the locality in question. From the standpoint of heavy hauling, highway systems generally act as short feeders for railroad freighting. This has been somewhat modified by motor truck development, as discussed later, but as far as long-distance hauling is concerned highways as a rule are not a large factor. However, long-distance freight hauling becomes a deciding factor for special districts removed from railroad facilities or for metropolitan districts with closely located cities. Light vehicles have a greater range of action and are not as closely confined to definite routes. Local topography modifies the various schemes but the traffic requirements usually result in a system of main roads radiating from shipping points, cities, county seats, etc., connected at proper intervals by cross roads. Each local system is tied to the adjacent system by a reasonably direct route. (See Fig. 13, Western New York State & County System.) (See Fig. 14, for Local System Monroe County.) The advantages of a complete plan of this nature is very evident. Single bond issues or appropriations are rarely comprehensive enough to complete even a skeleton system of roads for large areas but if a more or less complete system of

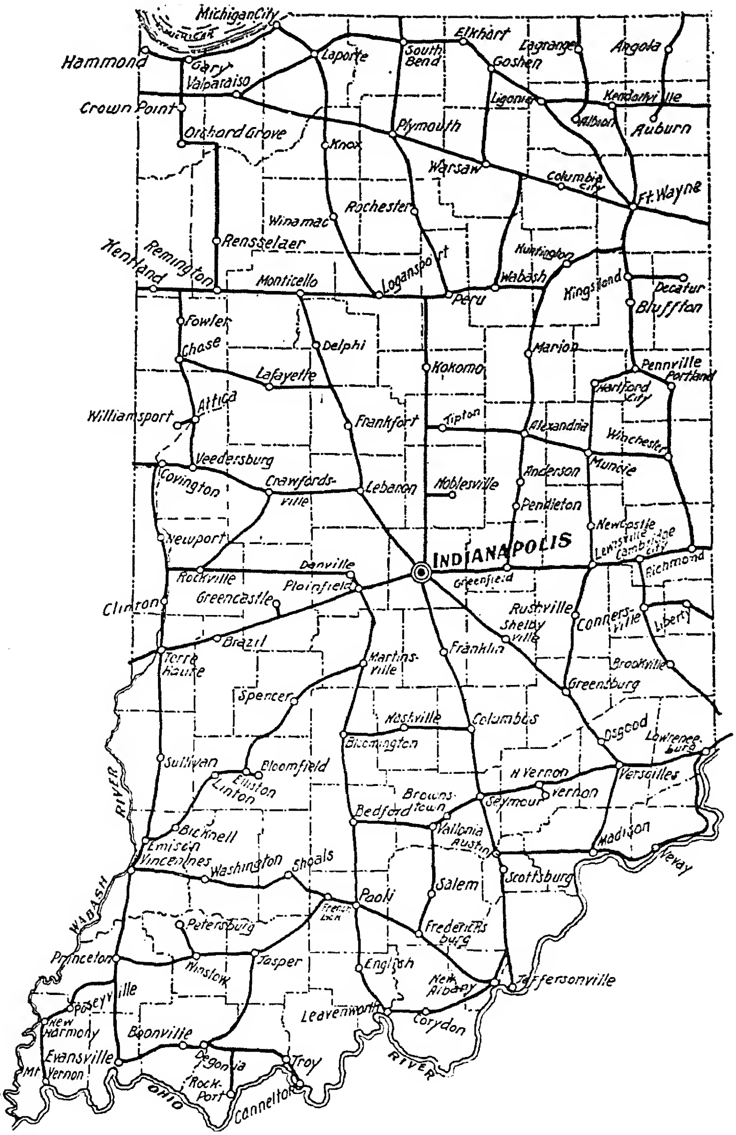


FIG. 12.—Indiana state road system. (Skeleton through routes.)

roads is laid out at the time the improvement program is started it is possible to see at a glance the part each road plays in the general scheme. This makes it easier to design individual roads to fit into the finished system, and it is also easier to decide on a reasonable order of construction.

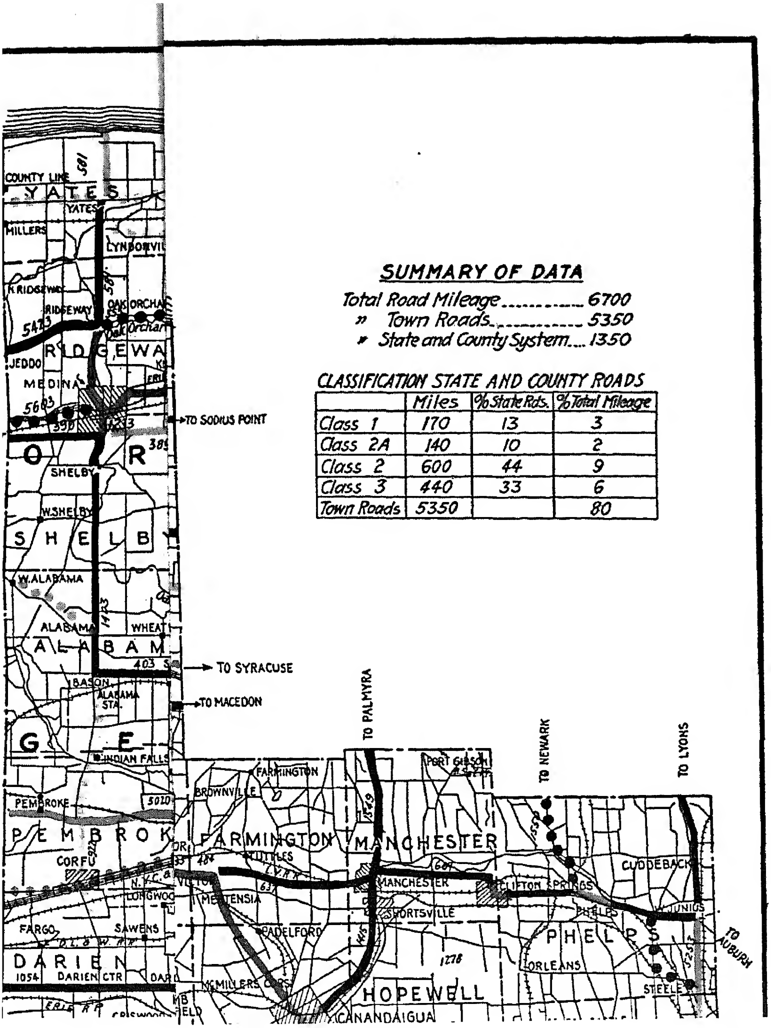
Systems are laid out by careful study of maps, field inspections of alternate routes, conferences with local people and sometimes are affected by traffic estimates on rival roads. The value of any proposed highway system can be roughly indicated by traffic counts; to illustrate, the State of Illinois concluded from such counts that 15,000 miles of her roads out of a total of 95,000 miles carried 90 per cent. of the total traffic. It should, however, be remembered that road improvements often change the movement of traffic and that existing traffic routes should not outweigh evident advantages of other locations. Such a count may not determine exactly which roads to improve, but it indicates that a well laid-out system containing 15,000 miles will probably give excellent service as a system of Main Roads.

Complete State or National Road maps may well be compiled showing the existing movement and volume of traffic (see page 45); the condition of existing roads and bridges; the location of road materials; the location of industries affected by highway haulage; the location and character of natural resources dependent on highways for their development. Such data aids reasonable layout and design. Preliminary data of this kind is rarely well worked out on account of the time and money required for careful study. The insistent demand for immediate construction regardless of where the dirt flies is responsible for many disappointing programs.

Classification of Roads.—Highways are classified in two ways; to apportion funds and to determine pavement type.

The classification as National, State, County or Town Highways depends on their location and relative importance to the present or future transportation needs of the country. Such a classification not only furnishes a reasonable basis for the apportionment of funds but it also provides a sliding scale of excellence for the design of the fundamental features of different classes of road improvements.

This does not mean that because a road is designated as a State or National road that it is necessarily entitled to expensive construction. Extensive State and National programs



SUMMARY OF DATA

Total Road Mileage 6700
" Town Roads 5350
" State and County System.... 1350

CLASSIFICATION STATE AND COUNTY ROADS

	Miles	% State Rds.	% Total Mileage
Class 1	170	13	3
Class 2A	140	10	2
Class 2	600	44	9
Class 3	440	33	6
Town Roads	5350		80

cover a wide range of construction from thickly settled districts to pioneer territory. The location and demands of existing traffic or the expected traffic in the near future control the desirable *present expenditure* on any road whether it is a town or national highway, but if the road is designated as a national route it is probable that in the future it will carry a large volume of traffic, and it indicates that the progressive stages of improvement may well provide liberally for right of way, alignment, grades, etc.

Classification for Financing.—A complete layout and classification scheme aids the proper apportionment of funds. The distribution of Federal, State and County aid to through routes and to local service roads is an extremely difficult problem from a practical standpoint but considering that about 90 per cent. of traffic is local, too much help or too much stress on the immediate completion of a skeleton system of through routes is open to question unless such routes can be located and built to act as the main arteries of local traffic. Unless the local service program is fairly well completed, large amounts cannot be reasonably spent on high priced connecting links through sparsely settled outlying districts which have very little value except for tourist travel. If no line of communication exists a moderate priced road is a good investment but excessive expenditures are to be avoided.

We have no system of National Highways as yet but in all probability it is only a matter of a short time before a start will be made. Federal Highway aid is an accomplished fact. The present law (1920) requires State or State-County co-operation and is laid out apparently with the idea of improving general administrative conditions in road programs. The actual construction done under this act includes local service roads as well as through routes, which is a sound proposition. Work of this kind can, however, be well supplemented by a National Trunk Line System, provided the local service program is not pushed into the background by the more spectacular through lines.

National Highways are naturally confined to the most important interstate routes or special highways necessary for military purposes. Some very ambitious programs of mileage have been proposed but it is not likely that such a system will aggregate over 1 to 2 per cent. of the road mileage of the country. Such roads may well be constructed and maintained by Federal

funds or by co-operation with the states under Federal supervision. The general principles of route selection later discussed govern the layout of these roads.

State Routes cover the main inter-city routes or the main natural transportation or tourist routes. They do not as a rule include more than 4 to 6 per cent. of the total road mileage. They are usually financed by State funds or may receive Federal Aid.

County roads include the main local service roads. They do not as a rule aggregate over 15 per cent. of the total road mileage. They are financed by county funds or may receive state or federal aid.

While National, State and County roads do not probably include more than 15 to 25 per cent. of the total mileage in the country, they probably carry from 80 to 90 per cent. of the total traffic during some portion of its journey.

Town roads constitute from 75 to 90 per cent. of mileage and while they are generally light traffic roads they act as feeders for the main system and are of very great economic importance to the general transportation scheme. It is certainly extremely poor policy to over-emphasize the value of the main roads and neglect the feeders. Expensive construction is not usually required on such roads but they should be passable the year round and any comprehensive road scheme must deal liberally with these light traffic local roads. Town roads are financed by town funds and may receive county or state aid but rarely federal aid.

Classification for Details of Construction Design.—The decision as to general type and width of pavement and section depends on the kind and volume of traffic expected in the near future. On any road the amount and class of traffic will fluctuate. The first improved roads in any locality may for a time carry more than their share of the travel, which is naturally reduced by the subsequent construction of adjacent improvements, or it may be increased by the linking up of isolated improvements into a continuous route of improved roads between large centers of population. It can be readily seen that it is difficult to judge the amount of traffic a new road will have and that a short time traffic census is valueless as a basis for a definite conclusion. The general design is usually based on a comparison of the behavior of different kinds of previously built roads that serve

districts similar to that under consideration and this can better be determined by a study of the locality than by a localized traffic census. Roads on which high type macadams or rigid pavements are suitable may be divided into four general traffic classes.

Class I.—Main trunk roads between large cities not over 100 miles apart along natural transportation routes which accommodate through truck freight traffic. Main radial roads for 5 to 40 miles out of cities of say 50,000 and upward and in the business section of villages which carry the concentrated farm and truck traffic of a large area and are subjected to continuous heavy load travel. A Class I road usually carries more than 2000 rigs per day in the busy season.

Class II.—Main through automobile routes at greater distances from the cities, which have a large touring car traffic and medium heavy farm traffic and some heavy trucking. A Class II road generally carries from 500 to 2000 rigs per day.

Class III.—Secondary or feeder roads and cross roads having a medium heavy farm traffic and light pleasure travel. Class III also applies to main roads in sparsely settled districts.

Class IV.—Pleasure or scenic roads that carry a large number of pleasure autos but light steel tire traffic.

Class I roads as a rule require rigid pavement construction while Classes 2, 3 and 4 are generally more economically served by thick modern bituminous or waterbound macadam (oiled) or gravel construction.

Value and Limitations of Traffic Census.—Complete traffic counts taken at regular intervals provide definite data concerning volume and character of traffic and the direction of its movement. Such a census has an indisputable value in indicating the general character of our highway traffic. Even the usual short time census has some value in determining the general character of the traffic. The usual short time census however has a very limited value in connection with definite decisions of design.

As far as design is concerned a well taken census can be given some weight when applied to a road system before an improvement program is started. It has a very decided value for use in reconstruction programs where the improved system has been completed and traffic routes established. It has practically no value for a partially completed system where traffic may go out of the way to use the first improved roads. Any traffic census should be fairly complete and represent the seasonal variations

of traffic. Detail methods are described in the second book of this series.

Take a concrete example to illustrate the discussion. (See Traffic Map, page 45).

This map applies to the partially completed state aid road system shown in Fig. 13, page 41. It was devised by Mr. Percy Waller of Rochester, N. Y. for use on Division No. 7 and is a much better method of summarizing the census than the usual tabular form. This particular map represents total volume of traffic. Similar maps can be prepared to indicate tonnage, or truck traffic, etc. It is a very effective way of showing the relative use of the roads and the distribution of travel at junction points. It is a valuable guide provided the data on which it is based is complete.

This particular map however was based on the usual New York State short time census taken for two days (Aug. 14th and 15th, 1920) from 7 A. M. to 7 P. M. On account of the limited scope of the data the census or any other similar census must be used with caution. Suppose we analyze the data.

The estimate does not show seasonal variation in classes of traffic (horse and motor).

It does not give a reasonable basis for total traffic considering seasonal variation and night travel.

It has some value in representing the relative traffic on the roads during the summer season but falls down in numerous instances on account of summer resort travel, special fairs, Dollar day at Batavia, special picnics and the fact that some of the shorter main line roads are not yet completed. That is, this census is not in itself complete enough to have much value and the road system is not near enough completed to give the probable traffic movement in some cases. If we had a 24-hour count for Monday in January, Tuesday in February, etc., we could eliminate much of the uncertainty provided the system was completed and the count was to be used in deciding on pavement types for reconstruction.

Suppose we cite a few cases where the traffic figures would be misleading unless modified by a common sense study of the territory.

In the first place the census was taken in the height of the auto touring season. It over-emphasizes the traffic on the through routes as compared with the secondary lines.

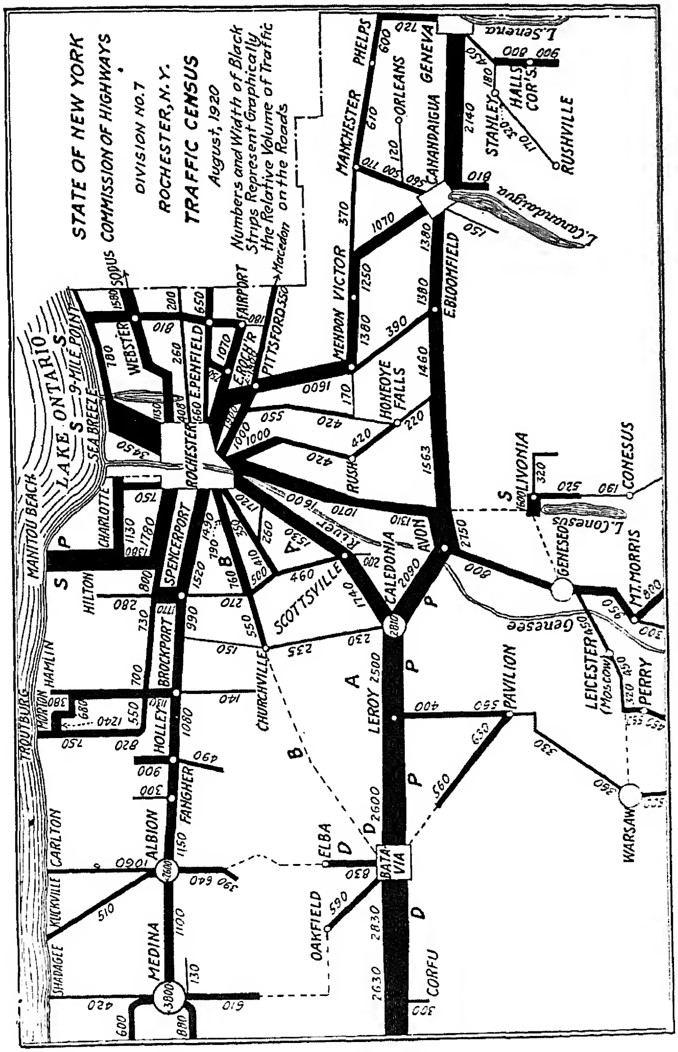


Fig. 15.—Traffic map.

A census taken in the winter, fall or spring months would probably show a larger percentage of horse traffic particularly on the local service roads.

The roads marked *S* are summer resort roads and a seasonal census would change the volume radically. The roads marked *P* where affected by large picnics or county fairs. Batavia had a dollar day sale, Caledonia had a fair and all the farmers flocked to town The roads were unusually crowded.

The road marked *A* will in the future be relieved by the completion of the road marked *B* which will radically change the volume on these roads.

On one unimportant road the local people asked a friend of mine to drive up and down as many times as he could to swell the count and said they were all doing it in order to help get a concrete resurfacing job on that road.

One or two of the roads are in such bad shape from a lack of maintenance funds that the traffic count was less than normal.

These points are mentioned to illustrate the statement that the most reliable basis for design of a road in a new or incomplete road program is a common sense study of the territory. A common sense study, however, includes a well-taken traffic census; not the usual incomplete count.

Example of Classification by Location and Census Combined.—A concrete example of a design classification by location and census is shown in Fig. 13 and explained as follows: Its value as a basis for a continuous policy is self evident. This particular territory is selected to illustrate the discussion as its problem is typical of the usual road conditions. It illustrates a wide range of conditions and with slight modifications will apply to most of the States. By means of a definite illustration we hope to strengthen the discussion of general principles.

The roads shown in red are class one, entitled to strong rigid pavement construction or reconstruction.

The roads shown in green are in the doubtful class designated 2A. The use of rigid pavements or high-class macadam depends largely on the relative cost for each road. Any reconstruction should provide for a low maintenance cost surface although the existing macadam base may be utilized if firm and solid.

The roads shown in black are class two, served most economically, in most instances, by a thick modern bituminous macadam, with reconstruction of the same type.

The roads shown in yellow are class three, on which the usual well-built modern waterbound macadam, maintained by surface oiling, will serve satisfactorily. The roads shown in green, black or yellow with red dots mean that a rigid pavement is desirable on account of water flooding and not on account of traffic action.

Such a classification should be carefully made utilizing the best judgment of the entire engineering force and local authorities. It should be reviewed and co-ordinated by the chief engineer. If well made and given enough publicity it tends to stabilize the general construction and reconstruction programs as any new administration would hesitate to change it radically unless they could make an excellent argument for so doing. One of the most troublesome difficulties that the highway engineer has to contend with is the constant change of general policy inaugurated by successive administrations and any method which tends to minimize such changes is a move in the right direction.

The tentative classification shown in Fig. 13 was made by the author with the help of five other engineers, some of the maintenence men and local officials. It was prepared to illustrate this manuscript. It is not an official classification. General plans of this nature are not yet in ordinary use but it is only a question of a short time before they probably will be.

In order to give an idea of the percentage of the different classes of road in the district shown, the following tabulation is inserted.

Road classification	Approx. percentage of state and county system, approx. total 1350 miles	Approx. percentage of total road mileage, approx. total 6700 miles
Class 1	13	3
Class 2A	10	2
Class 2	44	9
Class 3	33	6
Town roads	..	80

In order to show the range in classification for different territories the following tabulation shows Wyoming county (a poor district) and Monroe county (a rich thickly settled county).

WYOMING COUNTY

Road classification	Approx. per cent. of state and county system, approx. total mileage 175	Approx. per cent. total road mileage, approx. total mileage 1076
Class 1	4	1
Class 2A	0	0
Class 2	42	7
Class 3	54	9
Town roads	..	83

MONROE COUNTY

Road classification	Approx. per cent. of state and county system, approx. total miles 400	Approx. per cent. of total road mileage, approx. total miles 1368
Class 1	12	4
Class 2A	20	6
Class 2	42	12
Class 3	26	8
Town roads	..	70

The outstanding feature of this classification is the comparatively small mileage of roads requiring rigid pavements at this time (1920).

The value of a classification of this kind for design, apportionment of funds and appropriation estimates is illustrated as follows:

National Routes.—It is self evident that the natural location of a national route should follow along the New York Central Railroad via Corfu, Batavia, Bergen, Churchville, Rochester, Fairfort and east to Syracuse. Such a road is class 1 for the entire distance in this territory. (Fig 13, page 41).

State Routes (Fig. 13).—The state roads as actually built or proposed aggregate approximately 370 miles. To illustrate the statement previously made that the designation of a road as a state route does not necessarily entitle it to expensive construction, the tabulation below shows the approximate number of miles of such state routes under a reasonable classification.

	Approx. mileage	Per cent. of total
Class I	90	24
Class 2A	80	22
Class 2	160	44
Class 3	40	10

Comparison of Actual Construction with this Illustrative Classification (Fig. 13).—As a whole the actual construction designs are fairly reasonable for the various roads. We have some under-designed Class 1 roads and some over-designed Class 2A, 2 and 3 roads.

The main roads built between the years 1900 and 1912 would be classed today as under-designed. This is due to the remarkable increase in volume and weight of motor traffic. The secondary roads of this period are satisfactory even today. The increase in traffic, the change in its character and a lack of adequate yearly maintenance funds, resulted disastrously in some cases which caused a swing in sentiment to very expensive pavements even on Class 2 and 3 roads. For the last few years there is too much tendency to spend excessive sums on Class 2 and 3 roads. Class 1 roads are not over-designed and are in fact still under-designed. The more or less prevalent tendency to build $40,000 a mile roads on Class 2 and 3 highways tends to curtail needed mileage and is a very dangerous policy as it is liable to discredit State and National aid. We have been very much disturbed over too many cases of this kind and believe it well to emphasize the danger of such design.

Appropriation Estimates for Construction (Fig. 13).—By assuming a reasonable maximum expenditure for each class of road and not exceeding it when the road is put under construction, appropriations will more nearly accomplish what they are expected to do. The recent change in general price level has about doubled the cost of construction as compared to prewar conditions. This has caused a necessary curtailment of mileage for funds raised before the war but in a great many previous cases the lack of reasonable appropriation estimates resulted in failures to obtain anything like the mileage expected and has caused a great deal of dissatisfaction and in some cases discredited an improvement program.

For the district shown in Fig. 13 (1920 cost conditions) a tentative scale of costs per mile may be assumed as follows:

Class 1 not to exceed $50,000 on an average.
Class 2A not to exceed $40,000 on an average.
Class 2 not to exceed $30,000 on an average.
Class 3 not to exceed $20,000 on an average.

Main town macadam roads, $7000 to $10,000 on an average.

On this basis the complete state and county system, 1350 miles (Fig. 13), would cost approximately $41,000,000 exclusive of interest. This would be a fairly heavy burden but is not unreasonable with proper State and Federal aid if the construction period was stretched out over a reasonable term of years (15 to 20) and the twenty-five year serial method of financing used.

Funds for the original construction of such a system may well be raised largely by a general tax levy supplemented in some cases by vehicle taxes to help take care of the interest on the bonds.

The tentative scale of prices is for a rich district. For the first stages of improvement programs in poorer districts a lower order of improvement must be adopted. This is discussed in more detail in the second book of the series.

The following tabulations taken from the Highway Green Book of the American Auto Assoc., 1920, show the total cost and average yearly costs of serial bonds.

Total Cost of Serial Bond.—Total cost of a $100,000 serial bond bearing 3, 4, 5 or 6 per cent. interest and maturing at different periods from 5 to 50 years.

Term in years	3 per cent.	4 per cent.	5 per cent.	6 per cent.
5	$109,000	$112,000	$115,000	$118,000
10	116,500	122,000	127,500	133,000
15	124,000	132,000	140,000	148,000
20	131,500	142,000	152,500	163,000
25	139,000	152,000	165,000	178,000
30	146,500	162,000	177,500	193,000
35	154,000	172,000	190,000	208,000
40	161,500	182,000	202,500	223,000
45	169,000	192,000	215,000	238,000
50	176,500	202,000	227,500	253,000

Average Annual Cost Serial Bond.—Average annual cost of a $100,000 serial bond bearing 3, 4, 5 or 6 per cent. interest and maturing at different periods from 5 to 50 years.

Term in years	3 per cent.	4 per cent.	5 per cent.	6 per cent.
5	$21,800	$22,400	$23,000	$23,600
10	11,650	12,200	12,750	13,300
15	8,267	8,800	9,333	9,866
20	6,575	7,100	7,625	8,150
25	5,560	6,080	6,600	7,120
30	4,883	5,400	5,917	6,434
35	4,400	4,914	5,429	5,943
40	4,037	4,550	5,063	5,576
45	3,756	4,267	4,778	5,289
50	3,530	4,040	4,550	5,060

For a more complete discussion of Highway Bonds. (See Appendix A).

Prevailing Rates, General Road Tax.—In 1920 a state wide road tax was levied in 22 states varying from 1/10 to 4 mills. The general county road tax by towns for Monroe County, 1920 (this territory being used for illustrative discussion) varies from 2 to 5 mills and averages about 2½ mills.

Preliminary General Yearly Maintenance and Renewal Estimates (Fig. 13).—It is generally believed that the road user should pay a large proportion of money necessary for the upkeep of the highways. This includes maintenance and renewals as the pavements are worn out. A relatively small percentage of such funds may properly be raised from general tax funds but only a small percentage as the community at large have usually done their share by constructing the roads under a general tax levy.[1] To approximate the probable yearly burden that will fall on such users and that will be collected by auto licenses or some form of direct vehicle tax we may assume the following values for a road system that has been completed long enough to require the normal maintenance and reconstruction necessary to prevent deterioration in its value. The cost of maintenance, renewals and length of life of pavements is discussed in detail in the second volume of this series.

[1] This is discussed in more detail in the second book of the series.

Class 1 roads....................	Approximately $2500 per mile per year
Class 2A roads..................	Approximately $2200 per mile per year
Class 2 roads....................	Approximately $2000 per mile per year
Class 3 roads....................	Approximately $1500 per mile per year

On this basis for the district shown in Fig. 13 we may expect eventually a yearly expenditure of approximately $2,600,000 for maintenance and renewals of the main roads. To raise any such amount the auto license fees will have to be materially increased or some other form of tax adopted. The increase necessary is not however beyond the bounds of reasonable taxation.

The maintenance funds have never been adequate for this territory which results in excessive expenditures for reconstruction at intervals. Maintenance must be put on a business basis. The usual maintenance programs are often far from reasonable.

General Distribution of Tax Burden.—At a number of places in the text we have indicated the quite generally accepted principle of paying for the original construction of modern highways largely by general tax levy and for the maintenance and reconstruction of such highways largely by vehicle taxes. While this is believed to be essentially sound there is opposition and disagreement from different sources and it is perhaps just as well to summarize very briefly the basis for such a distribution of the improvement burden.

A successful tax program is based roughly on three main points.

First.—The final burden shall fall on each individual as nearly as possible in proportion to the direct and indirect benefit received.

Second.—The direct tax shall be paid by the individuals receiving the immediate direct benefit if they are financially able.

Third.—The tax must be levied on a definite source comparatively easy to assess and be collected from individuals having the ready money for payment.

No tax scheme works out without minor injustice. Libraries have been written on the subject but for this particular problem of road improvement one point of view may be expressed roughly as follows.

Real property, motor vehicles, tractor or horse vehicles are definite sources of taxation owned by individuals presumably with ready cash to pay any reasonable tax burden.

Most of the immediate and direct benefit of improved highways

is received by the owners of vehicles operating on the roads. The adjacent property owners and a small part of the community at large get some immediate benefit even if they are not direct road users.

Some of the final direct and indirect benefits of a modern highway system are as follows:

The improvement of the social and economic conditions of rural life which tends to prevent an unhealthy loss of rural population and stabalizes the fundamental relation of local food supply to healthy city development.

The development of the natural resources of sections dependent on highway transport.

The increase in the scope and power of the transportation system of the country which is at present taxed to the limit.

The cheapening of short haul transportation of food stuffs.

The raise in rural land values.

Added recreational possibilities for the community at large.

Military value in time of war.

A well constructed modern highway system promotes the general welfare of the entire nation and each individual whether a road user or not gets some direct or indirect benefit. The cities cannot get along without the country. An increase in prosperity of the rural districts increases the prosperity of the cities; an increase in the prosperity of one state has some effect on the prosperity of all the others. The nation can only develop on the principle that the prosperity of the country depends on the prosperity of even the new poor districts. This is the foundation for State and Federal Highway Aid.

The inauguration of a highway system is a benefit to every individual in the community. While the road user gets most of the direct benefit, it is rarely feasible at this stage of the improvement to tax him directly for a large proportion of the cost of construction. That is, before improved highways are an accomplished fact, the vehicles are fewer in number and operated by financially poorer individuals. The completion of a modern highway system increases the number and effectiveness of vehicles and adds to the ability and willingness of the owners to assume a larger tax burden. It is therefore generally believed that the original construction of such a modern system *under a proper classification based on reasonable regulation of traffic* should properly be paid for largely by a general real property tax levy

which is eventually quite evenly distributed over the community by rents, etc.

The cost of maintenance and the renewal of pavements depends on the volume and kind of traffic. The largest share of the benefit of keeping a road continually in excellent shape goes to the vehicle owner. There are two general classes of traffic, pleasure traffic and business traffic. If a pleasure vehicle is taxed a fair amount to cover the damage it does to the road, this is a luxury tax borne by the owner. If a business vehicle is taxed a fair amount to make the highway self supporting, the charge is added to the other operating costs which go into the price charged to the consumer and the public at large foots the bill. The principle of a vehicle tax for maintenance and renewal apparently has a sound basis in fairness. The minor practical difficulties in connection with justly applying this principle are no more serious than those encountered in the application of any other tax principle not essentially as sound so that any emphasis that may be placed on minor injustice of assessment has no real weight as an argument against the value of this basis for taxation. A large part of any possible injustice in its application can be reduced by a well thought out graduated license fee.

It is certain that if maintenance and renewal were paid by general tax levy that the pleasure traffic would escape its fair luxury tax and the business traffic particularly heavy hauling would have an unfair advantage in competition with other transportation methods which pay their own cost of track or waterway construction and maintenance. In 1919 the average motor vehicle license fee in the U. S. was approximately $9.00 and ranged from $5.00 per average motor vehicle to $20 per average motor vehicle. Horse drawn traffic paid no fees. It is very evident, particularly in the States which have constructed a large mileage of modern roads, that the present (1920) liscense fees are an entirely inadequate share of the highway tax burden and that so far vehicle owners of all kinds have escaped nearly scot free from their share of the burden. A moderate raise in license fees, not beyond the bounds of reason, gradually increasing as a road system grows will handle the situation satisfactorily.

Public road tolls are not feasible except for a few special cases as they restrict the free movement of traffic so that some form of graduated vehicle license seems the most reasonable form of tax

for a large part of the cost (say 80 per cent.) of the upkeep of highways.

Order of Construction.—The order of construction of individual roads dovetails in with the problem of apportionment and is also a fruitful source of trouble. Considering the third principle of design, *Local Service*, probably the safest policy where all the roads are in poor shape is to start the improvements from well-defined shipping points, county seats, cities, etc., and gradually extend the mileage until adjacent districts come together producing the finished through routes. If some of the existing roads are fairly satisfactory for traffic it is often desirable to modify this method by selecting the poor sections of the main roads for first consideration which eliminates the worst features of the system at once and results in quicker general use of the roads.

Selection of Route.—The selection of route depends on the purpose of the road, the topography between controlling points and the stage of development of the community. Each case is a special problem but there are certain fundamental facts worth considering. The basis of decision on general route rests on good common sense and is not entirely an engineering problem. The road must go where it will do the most good and it is up to the engineer to locate it in detail along the general route. The route location rests on reasonable answers to questions of the following nature: Where will the road do the most good to develop the natural resources of pioneer districts or how can we locate this route to serve the greatest number of people in well-settled communities or how can we build this scenic road to give the most pleasure? If an attempt is made to solve all these problems strictly on the basis of the shortest distance and the easiest grades *between terminals* we would be in hot water. Any satisfactory solution considers the broad engineering principles of short distances, reasonable grades and the smallest amount of rise and fall but the final decision does not always rest on close analytical ton mile cost hauling figures. To illustrate; recreational roads through national and state parks or forests are usually laid out to afford the most pleasure; grades and distance are sacrificed to obtain vistas, bold outlooks, and to reach points of historical interest or summer resorts. The cost of operating a car on such roads has no bearing on its usefulness and a location based on a close analytical ton mile hauling cost would be merely ridiculous. Suppose we consider a national

highway from New York to San Francisco. Some through touring will occur but its volume is very light and the cost of additional distance is not of any consequence to this class of traffic. More touring will go one-half or one-quarter of the way but even this is of no great factor in comparison with the short distance traffic on the route. To lay out any long route on the basis of the shortest distance and easiest grades between terminals for through traffic and to disregard passing through or close to the most cities and villages on the route is evidently poor policy. This illustration is exaggerated to bring out the principle of route selection in well-settled communities which is namely: *To pass through the most populous areas, and either close to or through the most cities and villages that can be consistently done without too much additional distance.* This same principle applies to state and to purely local roads and may be summed up as *direct contract with the greatest number of people.*

As the distance between controlling points becomes less the factor of commercial hauling has a larger bearing on the selection of route until we reach a point where the engineering requirements of location govern the selection. That is, a reasonably low ton mile hauling cost governs the short integral parts of any long route location. At the present time (1920) motor freight hauling in competition with railroads is rarely economical for a distance of over 80 to 100 miles between terminals. This limit will probably fluctuate but it is not likely to increase much and for the time being it does not seem desirable to permit the factor of long distance motor freight hauling to influence the selection of route between large cities directly connected by rail over 100 miles apart. Where large cities are located closer than this and there is a large volume of heavy motor hauling it is possibly better to save distance by omitting some of the local service. Where large cities are isolated heavy trucks rarely operate to outlying towns farther than 30 to 40 miles. Take a concrete instance to illustrate this principle (see Fig. 13, opposite page 41). Rochester, New York, a city of about 280,000 population is located 80 miles from Buffalo, a city of approximately 400,000 people. The first State Route completed between these cities is shown on Fig. 13 as far as Batavia, a city of 14,000 people, and is designated on this map as Route A. This route was laid out in conjunction with State Route 6, the main east and west route, on the principle of local service and it has served very satisfac-

torily for through traffic also. From the standpoint of through traffic between Rochester and Buffalo the route marked B on the map (Fig. 13) is the logical route and this will undoubtedly be built in the near future. That is, our experience indicates that it is better to first care for the local service and then in the future as the traffic requires it build new routes or partially relocate old routes for the further advantage of long distance travel. A comparison of these two routes between Rochester and Batavia follows and shows the distinct advantage of Route B from the standpoint of through travel and Route A for local service.

	Route A	Route B
Length, miles	37	31
Total rise and fall, feet	1850	1400
Number of railway shipping points served	15	9
Total railroad crossings	13	4
Railway grade crossings	9	1
Overhead or subway railway crossings	4	3

To give an idea of the traffic on this route in 1919 the following census (average 10 hour count in summer season) is shown at different points:

Route A

	Horse traffic		Motors		Total
	1 horse	2 horse	Cars	Trucks	
Between Rochester and Scottsville	30	30	850	100	1010
Between Scottsville and Caledonia	70	40	700	110	920
Between Caledonia and Le Roy	85	65	1600	180	1930
Between Le Roy and Batavia	15	10	1200	85	1310

As an additional point of interest the new proposed through Route B from Bergen to Batavia fails to pass through two small settlements Byron and South Byron because it would be necessary to use 2 miles extra distance for this local service. That is, Route B primarily considers through service. These villages can be served by a stub line. It is often desirable to by-pass villages and even certain cities on through routes on account of traffic congestion and the annoyance and danger of a large volume

of high speed traffic in the communities in question. These places can be served by stub lines or supplementary loops. As a rule, villages desire to have the main road pass directly through them on account of state aid in connection with their street paving and the additional business derived from traffic but the last feature does not amount to much unless they happen to be so

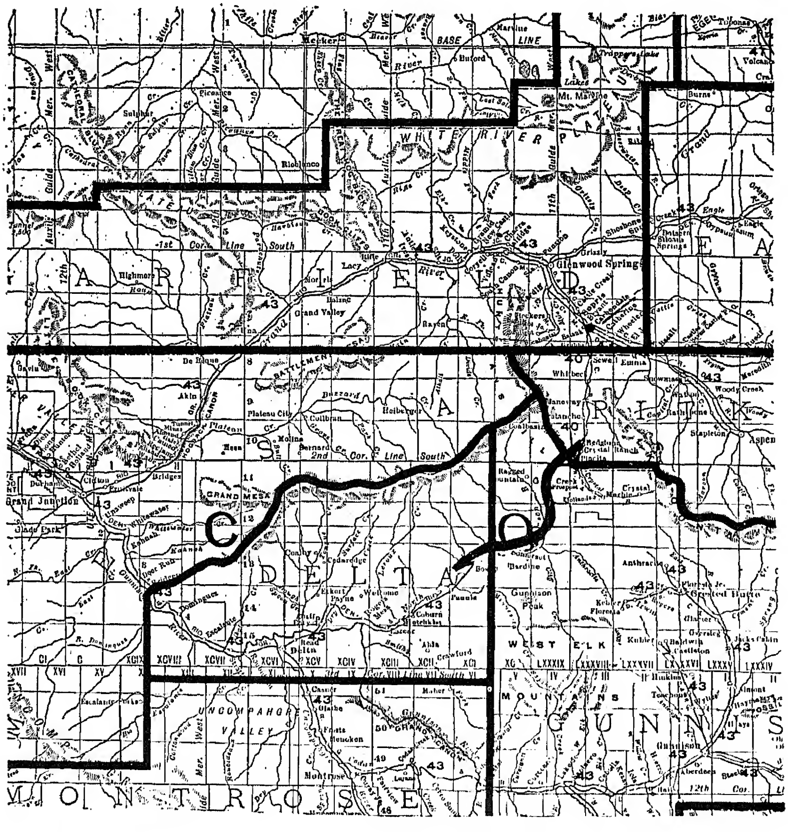


FIG. 16.—Bardine Redstone project (State of Colorado). Note how this road shortens the communication from Paonia to Carbondale.

located on the line that the traffic would naturally stop for some reason.

Pioneer Location.—To give an idea of the factors entering into the selection of route in mountain districts, an example will be cited in Colorado (see Fig. 16). The project referred to is the Bardine-Redstone road through the Sopris national forest.

This road was selected for improvement and advanced in order of construction by the U. S. Forest Service for the following reasons. An examination of the map will show that by a short road about 30 miles long over McClure's pass the Carbondale and Paonia valleys can be directly connected. Without this road, it took a day's travel by rail to get from Carbondale to Somerset. The second reason for the road was to open up a promising farming section along the upper Blackwater which had heretofore been confined to a cattle and sheep range on account of the impossibility of getting produce to the railroads. By the con-

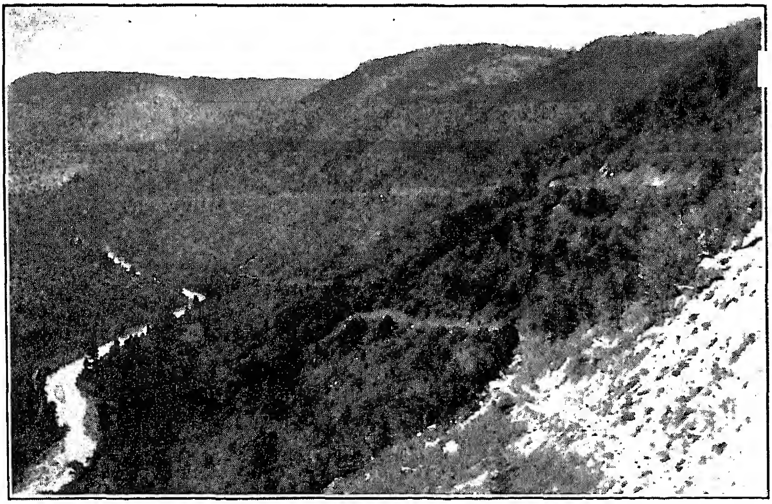


FIG. 17.—Example of engineering grade reduction. Pack trail in foreground. Newly located wagon road to the right and above. U. S. forest road project.

struction of moderately low cost natural soil road on a 5 or 6 per cent. grade over the low pass 3000 ft. above the valleys, intercommunication and new territory could be developed and a day's time in travel saved between two flourishing sections.

The foregoing discussion indicates in a general way some of the factors governing route selection.

Engineering Location.—A good detail location along the required general route results in the most effective road for the traffic that can be obtained for the available funds. We control our desires for perfection by the limitations of the community pocketbook. It is obviously desirable to obtain short distance, easy alignment, reasonable grades and to avoid locations which

call for extremely expensive construction such as rock work, flood areas, etc. It is obviously desirable to avoid locations where snow drifts badly or fails to melt promptly in the spring as the number of days in a year that a road is open has a large effect on its usefulness. A summary of the engineering principles of location are given on page 148.

Extreme Refinements Impracticable.—An economic engineering location for commercial roads might be theoretically developed on the lowest ton mile hauling cost to traffic. Practically it is not yet reasonable to do this in many cases for the ordinary highway and the reasons for disregarding this factor as the deciding element seem sound. Railroads have spent large sums to reduce the ton mile cost and in their location the engineers make extremely careful comparative estimates of construction cost against operating cost. They consider the elements of shorter distance, curvature, light and heavy grades, etc. Many railroad engineers wonder why these considerations are not given more weight on highway work considering the increase in mechanical transport. One of the evident reasons is that railroads get a direct tangible money return in dividends for their expenditure and the return to the community on a public road investment is too intangible. However, as a matter of interest we include a discussion of the approximate relation of distance, rise and time as it affects operating costs on pages 79 to 114. This data has been used by the author for some time as a basis for judgment in the comparison of lines.

It is undoubtedly true that to get the full value of an improved road system the engineering location must be made for the most efficient use of motor transport but at the present time there is no possibility of obtaining or any justification for spending extremely large sums to reduce the hauling cost below that obtained by the usual modern highway design. If we had unlimited funds provided by truck owners a careful analysis would be justified on special commercial roads but we must consider the following facts: the location of roads in well settled districts are practically confined to existing rights of way except for minor relocations to avoid extreme grades or for safety reasons; this is necessary as the community has grown up along these well set routes and the principle of direct contact holds. These rights of way were not necessarily laid out with any regard to economic road location and in fact are often arbitrarily fixed by land

section lines or locations where a poor road could be constructed in the past without much labor or cost. The cost of new rights of way for entire new locations and the difficulties of acquiring are prohibitive at this stage of development in road building except for unusual cases. The improved roads of today are only a progressive stage in the development of highway transport. The demand for them and the satisfaction in their use lies mainly in the fact that they provide a firm surface which can be used the year round, that they materially cheapen the cost of hauling that they make the use of light automobiles feasible for long and fast trips. The community is willing to pay a certain amount for the improvement in road conditions which the usual practice in modern road construction gives but it is not willing to pay large additional sums for further reduction in ton mile hauling costs. In the first place only a comparatively few men would get a direct benefit from such expenditure. The indirect return to the community is too intangible. Much of the road traffic is pleasure traffic and a few more gallons of gas means nothing. If the owner did not spend his surplus for gas, he would spend it for ice cream soda or the movies. There seems to be no way of making the few road users who would benefit by a further reduction in hauling cost pay the price of the necessary construction. It may be that for certain toll roads some time in the future or for exceptional present cases in metropolitan districts we can use a ton mile cost location analysis but we are not yet up to this standard for the usual road.

This does not mean that the engineer should not make an effort to get the best possible location that he can but he should bear in mind that the first principle of general policy considering a comprehensive road system is *Mileage Service* and aim to get the greatest mileage of road that will serve the purposes of the great majority of road users. For all roads except special service commercial roads probably 90 per cent. of the traffic does not demand nor would it be particularly benefited by excessive refinements. Poor grades or alignment should never be used on high class roads as they are the fundamental features of the improvement and the only permanent features of construction. Liberal expenditures are justified but there is a limit to expenditures for refinements that reduce mechanical operating costs to a minimum. The detail analysis of grade alignment section, etc. given in Chapters 4 & 5 are intended to bring out the re-

quirements of road design that are necessary for the satisfaction, safety, comfort and comparative cheap hauling requirements of the average road users. These are the fundamentals which must be provided.

We will attempt to show the road value of different limiting engineering requirements with their effect on construction cost. Additional refinements beyond the fundamental requirements are desirable if the funds are available from the proper sources. By the proper sources are meant the actual road users benefited by the additional cost of construction.

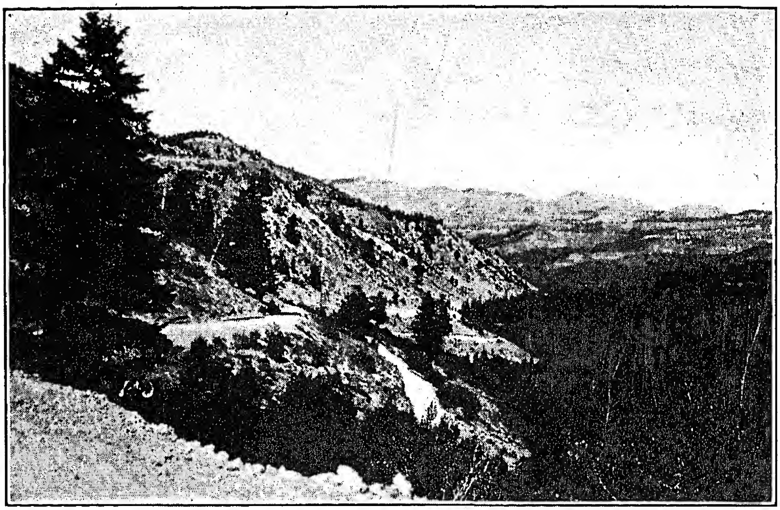


FIG. 18.—A Utah road location.

Saving in distance is valuable, saving in total rise is valuable, easy grades and the elimination of sharp curves are desirable. Every effort is made to accomplish these results utilizing the existing roads where we have to, making minor relocations to avoid extreme grade or danger because the sentiment of the community approves these measures but always bearing in mind that today and for a long time to come mileage is the prime requisite of programs. It is possible and desirable in the sparsely settled communities to make better engineering locations and for such districts we can more nearly accomplish a reasonable analysis as far as right of way handicap is concerned but in these districts shortage of funds often plays havoc with our intentions.

Value of Saving Distance and Rise.—It is well to bear in mind what distance saving is worth and what a saving in total rise is worth. The data given is, of course, of only general value as the fluctuating cost of motor operation, the types of hauling, special conditions of all sorts affect the figures. They, however, show in a general way that it is well worth while to reduce traffic losses arising from these elements of needlessly poor location or design.

Mr. A. R. Hirst gives the following conservative figures on the value of saving distance:

"If the very conservative sum of 10c. per mile is allowed for each mile of travel saved, the saving of a mile in distance on highways carrying the following average number of vehicles per day will save the traveling public the given amount per year, which is the interest at 5 per cent. on the amount given in the third column.

Value of a Mile in Highway Distance Saved

Average number of vehicles per day	Saving to owners per year	Saving capitalized at 5 per cent. equals
100	$ 3,650	$ 73,000
250	9,125	182,500
500	18,250	365,000
750	27,375	547,500
1,000	36,500	730,000
2,000	73,000	1,460,000
5,000	182,500	3,650,000
10,000	365,000	7,300,000

The value of eliminating rise cannot be figured with any degree of accuracy as there are too many indeterminate and variable factors but in the author's opinion it is not likely that the capitalized value of saving in yearly operation due to elimination one foot of rise and fall per 100 vehicles per day on long routes will exceed $30 on light grades or $400 on heavy grades. For small grading reductions on short hills the time factor is of no consequence and the practical value of saving a foot rise and fall is not probably more than one-third of these figures (see pages 79 to 114).

It is very evident that considerable expenditure is justified to reduce distance and rise but it is also evident that it would be impracticable to carry this method of location to its logical conclusion by expenditures in any way approximating the figures given. That is, the location of a free public road financed by a

general tax with no direct revenue return can hardly be analyzed from the same point of view as a trunk line railroad.

Relocations of Existing Highways.—We all would prefer to have scientifically located highways. A great many engineers believe that the time has come to make extensive relocations. It is self evident that relocations which reduce the construction cost of the proposed road as well as reduce motor operation costs should be made at once. It is surprising how often even

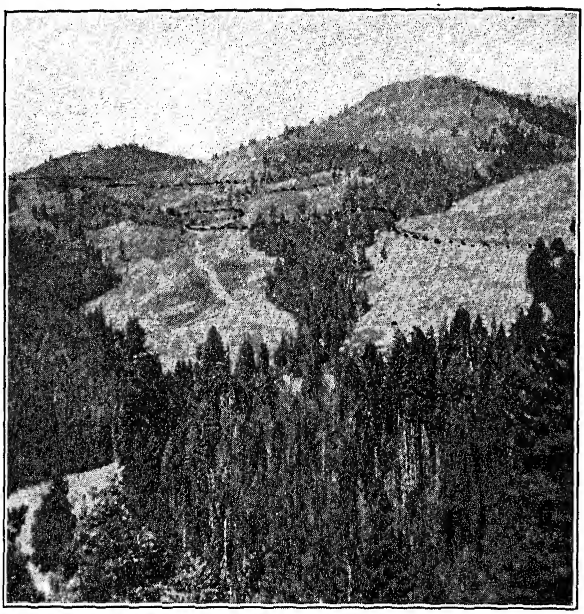


Fig. 19.—Relocation Galena-summit highway. U. S. forest road project (State of Idaho). Old road, 15 to 20 per cent. grades. New location (dotted line), 6 per cent. compensated on sharp curves.

Note.—Relocations of this kind are most certainly justified at the present stage of our highway programs.

such relocations are not made and it is desirable to impress on the men in charge of surveys that they should continually bear in mind the necessity of such relocations and not feel that they must follow the present road lines where these conditions prevail. There seems to be no question that expenditures for relocations necessary to obtain reasonably good grades and alignment are justified at the present stage of our road programs but the author believes that extensive relocations involving excessive

refinements must be gradually worked out except for a few extreme cases and that practically it will be easier to accomplish and fairer to the general public to do most of this work under *Reconstruction Programs* financed by direct vehicle taxes rather than to attempt it at this time.[1]

In case a relocation is necessary no halfway measures should be allowed. In too many cases even on fairly important state roads in rich communities relocations have been made on the basis of 9 per cent. grades when it was perfectly possible to get 7 per cent. or less. Halfway treatments of this kind are worse than nothing.

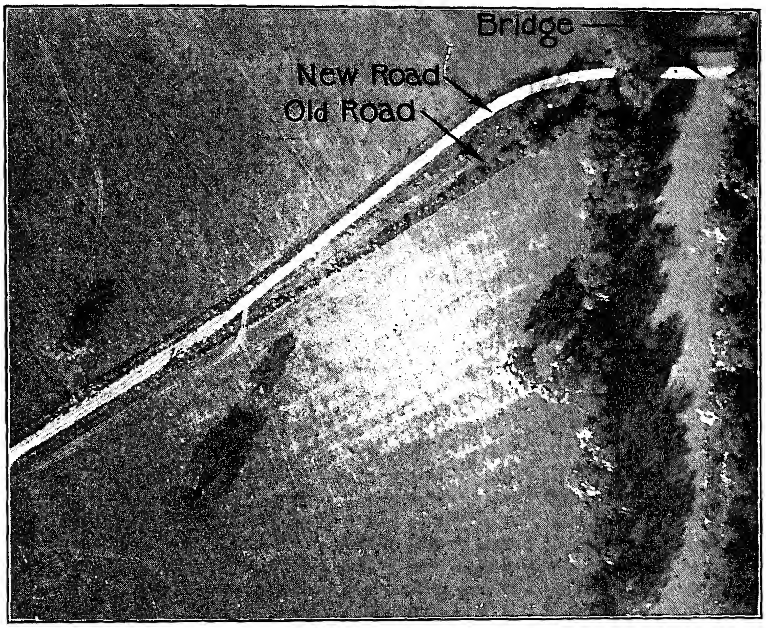


Fig. 19A.—Airplane view of bridge approach relocation (New York state). Minimum radius curvature old road 60′. Minimum radius curvature new road 570′. This relocation adds materially to the safety and convenience of travel.

To illustrate present practice on relocations the following quotations from the Iowa Highway Dept. Field Manual is given. The limiting grade of 6 per cent. mentioned does not agree with the author's recommendation given on page 116, but the general scope of the data strengthens the discussion at this point.

[1] See pages 104–107 for an approximate basis of comparing the value of alternate location.

Relocation.[1]—"Where the topography is flat or gently rolling the profiles readily lend themselves to satisfactory grades at a moderate cost, and relocations to any extent are seldom necessary. But in the rougher country relocations will frequently be necessary and the field man must constantly watch for opportunities to better the alignment, avoid steep hills, or improve stream crossings by relocations. The necessity for or advisability of relocating must always be balanced against the cost, and in general it is true that a proposed change of any magnitude is advisable only when it can be shown that such change will be economical or will produce a decidedly better road. It is therefore important that the cost of relocation be thoroughly investigated. In this connection the field man must remember to take into consideration the various improvements along the exsiting road, such as farm buildings, orchards, permanent bridges and culverts, heavy cuts and fills, etc.

The following instructions should be followed:

(*a*) In all cases where it appears that an excessive amount of earthwork will be required to reduce the present road to 6 per cent. grades, the possibility of relocations to reduce grades to 6 per cent. or less shall be fully investigated.

(*b*) In cases where there is a succession of grades which may be reduced to 5 or 6 per cent., but which cannot be reduced below that figure without considerable work, the question of relocation should be fully investigated.

(*c*) In case of doubt as to the feasibility of any relocation, a survey should always be made.

(*d*) In all cases where relocations are surveyed a survey shall be made on the old road also.

(*e*) In the case of minor relocations the margins of the old roadway should always be shown by a sketch indicating the old roadway by dotted lines, and by data in the cross section notes. In such cases the survey of the old road may consist only of extending the cross sections over the same.

(*f*) The notes shall show which location is to be used or shall state that the determination of which route to follow cannot be made until the notes are worked up in the office. The chief of party shall enter this notation in the field notes after consultation with the district engineer."

Conclusion.—Large bond issues have the habit of disappearing without accomplishing as much as they were expected to accomplish and any unusual feature of design, either location or pavement, which raises the average cost per mile must be used with caution. The great need of most localities is a fairly complete

[1] Iowa Highway Dept. Manual.

road system usable the year round. Until this is accomplished extreme refinements have a doubtful value.

Before large expenditures are made for unusual refinements in location it is just as well to get a reasonably complete mileage of good usable firm surfaced roads, as 100 miles of the usual modern improved road with reasonably good grades and alignment are more valuable to the community as a whole than 50 miles of more scientifically located highways. *Needlessly short mileage is the most serious criticism that can be made of any general policy dealing with an incomplete road system.*

It is not probable that the foregoing general discussion is of much interest to most of the younger engineers. It has been included more in the nature of a general survey of the problem. Nine-tenths of the road men are more interested in how to make a detail design of a definite road. The detail theory of design will be taken up in the following order: Grades, alignment, sections, drainage (pavements, Vol. 2.)

CHAPTER IV

GRADES AND ALIGNMENT

GRADES

Grade line design considers the proper use of maximum, minimum, intermediate and adverse grades and their vertical curve connections. Grade line design in connection with alignment considers the relative values of distance against rise and fall.

The effect of grade may be roughly summarized as follows:

An increase in the rate of grade decreases the load that can be hauled up the grade for a fixed power.

An increase in the rate of grade increases the expenditure of energy to maintain a fixed speed climbing the grade.

An increase in the rate of grade decreases the speed for a fixed power.

An increase in the rate of grade increases the wear and tear on mechanical outfits.

The mechanical energy expended in climbing is partially balanced by the reduction of energy expended on down grades.

The mechanical energy expended in climbing affords a very definite basis of comparison of the value of travel in one direction. The expenditure of energy on down grades is indefinite and while it effects the total operating cost on a grade it cannot be given as much weight in the conclusion as the first method. The effect of grade on the depreciation and repair of mechanical equipment is indefinite but it is certain that it bears some relation to the rate of grade.

Grade selection depends on considerations of safety, convenience, traffic operating cost, and the cost of construction and maintenance. Cost of traffic operation is not always the most important factor. It must often give way to considerations of safety or initial construction cost.

Reasonably low rates are desirable. The whole question of grades lies in the decision of what is reasonable for a specific case.

A summary of practical rules for location and cut and fill grade line design is given at the end of the chapter.

Maximum Grades.—Suppose we consider the subject of maximum grades from the following standpoints:

1. Relative importance of horse and automobile traffic in the selection of grade.
2. Effect of grade on horse traffic.
3. Effect of grade on motor traffic.
4. Current practice in maximum grades.
5. Practical considerations governing the selection of grade.
6. Effect of ruling grade on cost.
7. Recommended general practice.

Relative Importance of Horse and Auto Traffic in the Selection of Maximum Grade.—Tables 2 and 2A show the rapid growth of motor traffic on the main roads of Massachusetts and the general character of the traffic on secondary roads in Western New York.

TABLE 2

	1912	1915	1918	Per cent. of increase 6 years
Automobiles and trucks...	50,132	102,633	191,019	280
Motor cycles............	5,034	9,520	12,708	150
Operators and chauffeurs.	65,600	133,700	225,272	240
Motor vehicle fees.......	$616,236	$1,235,723	$2,159,257	250

AVERAGE DAILY TRAFFIC ON MAIN ROADS IN MASSACHUSETTS

	1909	1912	1915	1918	Per cent. of increase, 9 years
Light horse.................	91	68	40	24	$-73\frac{1}{2}$
Heavy horse.................	88	88	72	43	-51
Total horse................	179	156	112	67	$-62\frac{1}{2}$
Automobiles and light trucks.	131	280	555	923	+604
Heavy trucks...............	...	17	45	75	+341[1]
Total motors..............	131	297	600	998	+661
Total vehicles............	310	453	712	1,065	+243

[1] In 6 years.

PER CENT. OF TOTAL TRAFFIC

	1909	1912	1915	1918
Light horse	29	15	5½	2
Heavy horse	28	19	10	4
Total horse	57	34	15½	6
Trucks	..	4	6½	7
Motors	43	62	78	87

TABLE 2A.—DAILY TRAFFIC COUNTS ON SELECTED "LOCAL SERVICE" STATE COUNTY ROADS IN WESTERN NEW YORK

Number of roads	Number of miles	Horse traffic			Motor traffic		
		1 horse	2 horse	Total horse	Light cars	Trucks	Total motors
14	60	45	39	84	250	36	286

Horse traffic per cent. of total 23
Motor traffic per cent. of total 77

NOTE.—On the main State Route Roads the percentage of horse traffic corresponds very closely with the Massachusetts results given in Table No. 2.

We are all familiar with this change in the character of highway traffic. Maximum grades have a radically different effect on horse and single unit motor traffic and it is necessary to come to some reasonable conclusion as to which kind of travel should govern the design. There is a strong tendency to consider grade line design from the standpoint of single unit motor hauling on account of the predominance of this traffic on improved roads. As far as distance and total rise and fall are concerned this is probably sound. As far as rate of grade is concerned the author has no hesitation in saying that he considers it better to give horse traffic the preference on all town and county roads and that the conclusions as to grade that will be satisfactory for horse traffic will probably satisfy motor traffic on most state and national routes also. This conclusion is based on a number of factors. As long as horses are used for general farm utility they will be used for some hauling even under conditions favorable for

trucks (see Table 2A). In the northern states snow and ice handicap motor transport for a portion of the year particularly on side feeder roads. It is not likely that horse traffic will be entirely eliminated from our improved roads. Maximum grades limit the load a team can haul but they do not handicap single unit truck operation on firm surfaced roads as all the light and heavy motors have sufficient excess power to haul their rated load up any grade within reason. Steep grades do limit the application of the long trailer train mode of hauling. Where this method is popular or where special conditions make its adoption likely maximum grades may well be reduced below even the rates considered satisfactory for horse traffic. The long trailer train, however, is not a general utility system and need not as a rule determine the ruling grades except for a few special service roads. Long steep grades do affect the ease of motor traffic by forcing the driver to drop into second or low gear but they do not reduce single unit truck capacity nor do they have much effect on fuel consumption provided the total rise and fall and distance between terminals is the same.

It therefore seems safer to design maximum grades for a reasonable load for the weaker mode of hauling and in this way satisfy all classes of traffic. The final selection of grade is also affected by considerations of safety, convenience and the cost of construction and maintenance.

MAXIMUM GRADES FROM THE STANDPOINT OF HORSE TRAFFIC

Difficulty of Ascent and Safety of Descent.—The factors controlling ease and safety of ascent and descent have different values for different surfaces, but as most of the roads will in time be hard surfaced and as all parts of the design should fit into the final improvement, this part of the grade argument is made primarily for hard surfaced conditions.

European observers claim that on a stone road 5 per cent. is the maximum grade that can be descended safely by a trotting team without brakes and that 12 per cent. is the maximum that can be safely descended with brakes. By the use of the sliding shoe or locked wheels freighters in the Rockies descend 20 per cent. grades without much difficulty on ordinary natural soil roads. Safe descent with brakes need not be considered except in rare cases as it would result in a grade far beyond ordinary

practice. Safe and easy descent without brakes is more important for light rigs than for heavy hauling but as this class of traffic has been practically eliminated by cheap automobiles it need not be given much weight. Descent, therefore, plays only a minor part in grade selection except where the alignment is bad.

Hauling Power.—The writer knows of no careful records of actual maximum loads that can be hauled up different hard surfaced grades by an ordinary team; it is probably better to discuss this point theoretically as any experiments would be affected by too many variable local conditions to be worth much as a basis of comparison. As a check on the theoretical discussion records of loads on extreme mountain grades are given on page 78 which show that for all practical purposes, Table 8 of theoretical loads is fairly close and is on the safe side.

A summary of Prof. I. O. Baker's discussion of maximum team loads is given below, and through his courtesy we are enabled to include a collection of tables taken from his work, "Roads and Pavements."

Various trials have determined that the normal tractive power of a horse traveling three miles per hour for ten hours a day is approximately one-tenth of its weight; that when hauling up a steep grade it can exert one-fourth of its weight for a short time; that for a continuous exertion of one-fourth, the grade should not be over 1200 ft. long and if over that, resting places should be provided every 600 to 800 ft.; that in starting and for a distance of 50 to 100 ft., one-half of its weight can be used; and that the net tractive power ordinarily exerted by a horse on a grade equals (¼ its weight) — (the effort required to lift itself) or approximately $(0.25\ W) - (W \times$ per cent. of grade expressed in hundredths), *i.e.*, $(0.25\ W - 0.04\ W)$ for a 4 per cent. grade. This undoubtedly gives a reasonable basis for ordinary hauling conditions but from data obtained by the author in connection with freight hauling in mountain regions it is evident that a good draft horse will exert more than $0.25\ W$ on moderately short sharp pitches of a long climb if allowed to rest at intervals of 200 to 300 ft. The evidence indicates that a value of $0.35\ W$ is about right for such conditions.

Table 3 shows the effective power developed by an ordinary team of 1200-lb. horses with moderate exertion and Table 3A the power of a first class team of 1600-lb. horses exerting their full strength.

TABLE 3.—ORDINARY STOCK MODERATE EXERTION

	Grade, per cent.	Theoretical net tractive effort	Tractive effort in lbs.
	Level	$0.10\ W$	240
	2½	$0.25\ W - PW$	540
W = weight of team 2400 lbs.	4	$0.25\ W - PW$	504
	5	$0.25\ W - PW$	480
P = per cent. of grade in hundredths.	6	$0.25\ W - PW$	456
	7	$0.25\ W - PW$	432
	8	$0.25\ W - PW$	408
	9	$0.25\ W - PW$	384
	10	$0.25\ W - PW$	360

TABLE 3A.—DRAFT STOCK FULL POWER

	Grade, per cent.	Theoretical net tractive effort	Tractive effort in lbs.
	5	$0.35\ W - PW$	960
	6	$0.35\ W - PW$	928
	7	$0.35\ W - PW$	896
W = weight of team 3200 lbs.	8	$0.35\ W - PW$	864
	10	$0.35\ W - PW$	800
P = per cent. of grade in hundredths.	12	$0.35\ W - PW$	736
	14	$0.35\ W - PW$	672
	16	$0.35\ W - PW$	608
	18	$0.35\ W - PW$	544
	20	$0.35\ W - PW$	480
	22	$0.35\ W - PW$	416

Grade and Rolling Resistance.—This power is used in overcoming axle friction, gravity resistance and rolling resistance.

The axle friction is small amounting to three or four pounds per ton for American farm wagons.

Grade resistance (gravity) equals (load × per cent. of grade expressed in hundredths) and expressed in pounds per ton of load equals ($2000 \times P$).

The rolling resistance varies for different surfaces and for each surface depends on the diameter of wheel, width of tire, speed of travel and the presence or absence of springs on the wagon. The best diameter of wheels, best width of tires and the use of springs as they affect the ease of hauling for both farm and road use are problems for the wagon manufacturers.

Morin, a French engineer, concluded from a series of careful experiments that the harder the surface of the road the less effect width of tire had on rolling resistance. We are arguing from the standpoint of comparatively hard surfacing and are dealing with small differences in wheel diameter and can disregard these factors. As a matter of interest Tables 4 to 6 are

TABLE 4.—EFFECT OF WIDTH OF TIRE UPON TRACTIVE POWER[1]
Resistances in Pounds per Ton

Ref. No.	Description of the road surface	Diameters of the front and rear wheels respectively									
		3′–6″ & 3′–10″		3′–6″ & 3′–10″		3′–8″ & 4′–6″		3′–6″ & 3′–10″		3′–8″ & 4′–6″	
		Width of tires									
		1½″	4″	1½	4″	1½″	4″	1½″	3″	1½″	3″
1	Sod	...	...	...	...	...	...	283	239	189	228
2	Earth road (hard)	...	108	...	...	...	...	152	152	114	114
3	Earth road (muddy)	...	243	268	304	236	254	...	...	265	228
4	Sand road (hard)	199	162	171	164	141	168				
5	Sand road (deep)	371	351								
6	Gravel road (good)	...	. .	98	117	83	80	...	...	66	76
7	Wood block (round)	51	49	61	70	35	46	...	54	28	38

[1] Pamphlet by Studebaker Brothers Manufacturing Company, 1892.

TABLE 5.—EFFECT OF SIZE OF WHEELS ON TRACTIVE RESISTANCE[1]
Pounds per Ton

Ref. No.	Description of road surface	Mean diameter of front and rear wheels		
		50″	38″	26″
1	Macadam, slightly worn, fair condition	57	61	70
2	Gravel road, sand 1 in. deep, loose stones	84	90	110
3	Gravel road, upgrade 2.2 per cent., ½ in. wet sand, frozen below	123	132	173
4	Earth road. Dry and hard	69	75	79
5	Earth road. ½ in. sticky mud, frozen below	101	119	139
6	Timothy and blue grass sod, dry grass cut	132	145	179
7	Timothy and blue grass sod, wet and spongy	173	203	281
8	Cornfield; flat culture across rows, dry	178	201	265
9	Plowed ground; not harrowed, dry and cloddy	252	303	374
10	Average value of tractive power	130	148	186

[1] Experiments of Mr. T. I. Mairs at the Missouri Agricultural Experiment Station.

included to show the results of experiments on different soils and roads.

The question of wide tires affects road design chiefly in connection with the distribution of load over a safe area and will be taken up under "Foundations" (second book of this series).

TABLE 6.—TRACTIVE RESISTANCE OF BROAD AND NARROW TIRES[1]
Resistance in Pounds per Ton

Ref. No.	Description of road surface	Width of tire		No. of trials
		1½"	6"	
1	Broken stone road; hard, smooth, no dust, no loose stone	121	98	2
2	Gravel road; hard and smooth; a few loose stones	182	134	2
3	Gravel road; hard, no ruts, large quantity of sand	239	157	1
4	Gravel road; new gravel, not compact, dry	330	260	1
5	Gravel road; wet, loose sand 1 to 2½ in. deep	246	254	2
6	Earth roads. Loam, dry, loose dust 2 to 3 in. deep	90	106	2
7	Earth roads. Loam, dry and hard, no dust, no ruts, nearly level	149	109	3
8	Earth roads. Loam, stiff mud, drying on top, spongy below	497	307	1
9	Earth roads. Loam, mud 2½ in. deep, firm below	251	325	1
10	Earth roads. Clay, sloppy mud, 3 to 4 in. deep, hard below	286	406	1
11	Earth roads. Clay, dry on top but spongy below	472	422	2
12	Earth roads. Clay, dry on top but spongy below	618	464	5
13	Earth roads. Clay, Stiff deep mud	825	551	1
14	Mowing land. Timothy sod, dry, firm, and smooth	317	229	1
15	Mowing land. Timothy sod, moist	421	305	1
16	Mowing land. Timothy sod, soft and spongy	569	327	1
17	Pasture land. Blue grass sod, dry, firm, and smooth	218	156	2
18	Pasture land. Blue grass sod, soft	420	273	2
19	Pasture land. Blue grass sod, soft	578	436	1
20	Stubble land. Corn stubble, no weeds, dry enough to plow	631	418	2
21	Stubble land. Corn stubble, some weeds, dry enough to plow	423	362	1
22	Stubble land. Corn stubble, in Autumn, dry and firm	404	256	2
23	Plowed land. Freshly plowed, not harrowed, surface rough	510	283	1
24	Plowed land. Freshly plowed, harrowed, smooth, compact	466	323	1

[1] Missouri Agricultural Experiment Station Bulletin No. 39.

Table 7 gives the average rolling resistance in pounds per ton of load on different pavements for the ordinary farm wagon driven at ordinary speeds.

Effect of Grade on Loads.—For a comparative estimate we will take a value of 40 lbs. per ton of load, including axle friction, on macadams and rigid pavements and 100 lbs. per ton for earth roads in fair shape. The resistance to the effective tractive

TABLE 7[1]

Kind of pavement	Rolling resistance in lbs. per ton of load
Asphalt	30 to 70
Brick or concrete	15 to 40
Cobble stones	50 to 100
Earth roads	50 to 200
Gravel roads	50 to 100
Macadam roads	20 to 100
Plank	30 to 50
Stone block	30 to 80
Wood block	30 to 50

[1] Baker's "Roads and Pavements."

power of the team per ton of load is therefore $40 + (2000 \times P)$ on hard surfaced roads, and $100 + (2000 \times P)$ for earth roads, and the maximum load expressed in tons for any grade equals

$$\left(\frac{\text{Effective tractive power of team for that grade}}{\text{Resistance per ton of load for that grade}}\right)$$

Using the tractive powers of the ordinary team shown in Table 3, the following table is constructed. It is chiefly useful for a comparison of the effect of grade on load but all evidence indicates that the loads given correspond closely to practice. Table 8A shows loads for extreme team exertion as compiled in Table 3A. The loads given include weight of wagon.

TABLE 8

Grade, per cent.	Effective tractive effort, lbs.	Improved roads		Earth roads	
		Resistance in lb. per ton of load	Maximum load in tons	Resistance, lb.	Max. load, tons
Level	240	40	6.0	100	2.4
2½	540	90	6.0	150	3.6
4	504	120	4.2	180	2.8
5	480	140	3.4	200	2.4
6	456	160	2.9	220	2.1
7	432	180	2.4	240	1.8
8	408	200	2.0	260	1.6
9	384	220	1.7	280	1.4
10	360	240	1.5	300	1.2

TABLE 8A.—DRAFT STOCK EXTREME EXERTION

Grade, per cent.	Effective tractive effort lbs.	Hard surfaced roads		Earth roads	
		Resistance in lb. per ton	Maximum load in tons	Resistance in lb. per ton	Max. load in tons
5	960	140	6.8	200	4.8
6	928	160	5.8	220	4.2
7	896	180	5.0	240	3.7
8	864	200	4.3	260	3.3
10	800	240	3.3	300	2.7
12	736	280	3.0	340	2.2
14	672	...	...	380	1.6
16	608	...	...	420	1.4
18	544	...	...	460	1.2
20	480	...	...	500	1.0
22	416	...	...	540	0.8

Effect of Length of Grade on Maximum Load.—In mountain road design where a long ruling grade is used it is often economical to introduce short stretches of steeper grade to avoid extremely expensive construction and to improve alignment. In order to determine the maximum short grade (not exceeding 300 ft. in length) that can be used in connection with a long ruling grade without reducing the team load we have compiled Table 8B for a 2400-lb. team.

TABLE 8B.—EQUIVALENT LONG AND SHORT GRADES FOR HARD SURFACED CONDITIONS

Long Ruling Grades Tractive effort 0.25 W 2400 lb. team		Short Maximum Grades Tractive effort 0.35 W 2400 lb. team	
Grade, per cent.	Maximum load, tons	Grade, per cent.	Maximum load, tons
5	3.4	7	3.7
6	2.9	9	2.8
7	2.4	10[1]	2.5
8	2.0	12	2.0

[1] 12 per cent. is the practical limit (on account of safe descent) on any road of sufficient importance to be considered from an engineering standpoint.

This principle can also be applied to a long cut and fill grade reduction with a very material saving in cost but if used the steeper rate should not be over 250 to 300 ft. long and should be at the bottom of the hill.

RECORDS OF TEAM LOADS

We are indebted to Mr. H. G. McPheters and F. F. Roberts for the following data on team freighting in the Rocky Mountain region. It is practical data obtained from personal experience and strengthens the force of the theoretical discussion. The loads given are net and do not include wagon weights. They represent usual freighting loads which are practical maxima.

Heber Fruitland Road, State of Utah

Daniels Canyon Section

Earth road in fair shape.
Long 8 per cent. grades.
Short 15 per cent. grades.
Net load for four horse team 3500 lb. (during summer).

Galena Summit Road, State of Idaho

(See Illustration, page 64)

Natural soil road in fair shape
Maximum grade (Salmon River side) 20 per cent.
Maximum grade (Wood River side) 17 per cent.
Load for one team 1800 lb. (during summer).
Load for two teams 4000 lb. (during summer).
Load for three teams (six horses and two wagons loaded 5000 lb. on lead wagon and 4000 lb. on trail taking one wagon at a trip up the mountain.)

Trail Creek Summit Road, State of Idaho

Natural soil road (fair condition during summer).
Maximum grade 22 per cent.
Load for one team 1200 lb.
Load for two teams 2500 lb.
When freighting by teams was the principal mode of transportation, there were used on this road several outfits of twenty-four mules hooked to four wagons loaded about as follows: Lead 14,000 lb.; lead swing 10,000 lb.; swing 8,000 lb. and trail 4000 lb. Two men handled the whole outfit which was certainly a man's job.

Rocky Bar Atlanta Road Over Bald Mountain

Natural soil.
Maximum grade 16 per cent.
Load for one team 2000 lb.
Load for two teams 4000 lb.
A large amount of freight is carried over this road by auto trucks at the present time.

The Theoretical Advantage of Certain Grades.—From Tables 8, 8A and 8B and the previous discussion we can pick out the grades that theoretically fulfill certain traffic requirements.

I. On hard surfaced roads the same load that can be drawn up a 2½ per cent. grade by reasonable extra exertion of a team, can be hauled on a level with ease. This makes a perfectly balanced design from the standpoint of team hauling. The theoretical load is six tons. For earth roads 5 per cent. fulfills this same condition with a theoretical team load of 2.4 tons.

II. Five per cent. is the maximum grade that fulfills the requirement of safe descent at a trot without brakes. This is of little importance under modern traffic conditions.

III. The same load that can be hauled up a 7 per cent. hard surfaced grade can be drawn on a level dirt road in fair condition; a 7 per cent. grade therefore does not reduce the load of a team which must travel over even a level earth road for part of the distance. The theoretical load is 2.4 tons.

IV. The use of short maximum grades of greater rate than the long ruling grades does not reduce the maximum load provided they are proportioned as follows for hard pavements and do not exceed 250 ft. to 300 ft. in length.

Long..................	5 per cent.	Short.................	7 per cent.
Long..................	6 per cent.	Short.................	9 per cent.
Long..................	7 per cent.	Short.................	10 per cent.
Long..................	8 per cent.	Short.................	12 per cent.

V. Twelve per cent. is the practical limit of grade for even unimportant roads on account of safe team descent with heavy loads.

As a matter of fact the selection of grade depends more on the requirements of the traffic and the topography of the country than on these theoretical advantages.

Effect of Grade Selection on Motor Traffic.—It is not possible with the data at hand to analyze the cost of motor operation closely for different rates of grade but certain fundamental principles of road location can be established by the principles of mechanics modified by judgment.

Reduction in distance, time of travel and needless rise and fall are desirable but it is very difficult to put a money value on such savings particularly the elements of time and rise.

Practically, a little extra gas means nothing to a large pro-

portion of road traffic and a little extra time means even less, for we all waste a good share of our time despite the teachings of efficiency. Therefore to attempt to place a construction value on the saving of a little fuel and time hardly looks reasonable for most conditions. Under certain conditions, however, such as long distance main roads particularly where regular systematic truck freighting occurs the time element is a real factor and should be considered. The author has been in the habit of eliminating the time factor in considering motor traffic on Local Service roads but gives it some weight for Special Service Commercial roads. This, as a general rule, means that about twice as much expenditure is theoretically justified for saving distance and about three times as much for saving rise on Special Service roads as on Local Service Roads.

The discussion will first develop certain general principles of principles of location and then a rough approximation of operating costs on different grades. The theoretical discussion is followed by data modified for practical use. (See table 12*B*.) The author hesitated to include tables 11 to 12*B* in this book but finally decided to do so largely as a matter of academic interest as it is necessary for some one to make a start along these lines. The tables will undoubtedly be subjected to severe criticism. They can most certainly be improved by investigation and experiment but they have been used for some time as a basis for judgment and their application has resulted in what appears to be rational conclusions. They certainly demonstrate general principles of design and their use for detail conclusions is better than guesswork. They are submitted as a pioneer attempt which I hope will arouse discussion and further experimental investigation.

EFFECT OF MAXIMUM GRADE ON MOTOR TRAFFIC

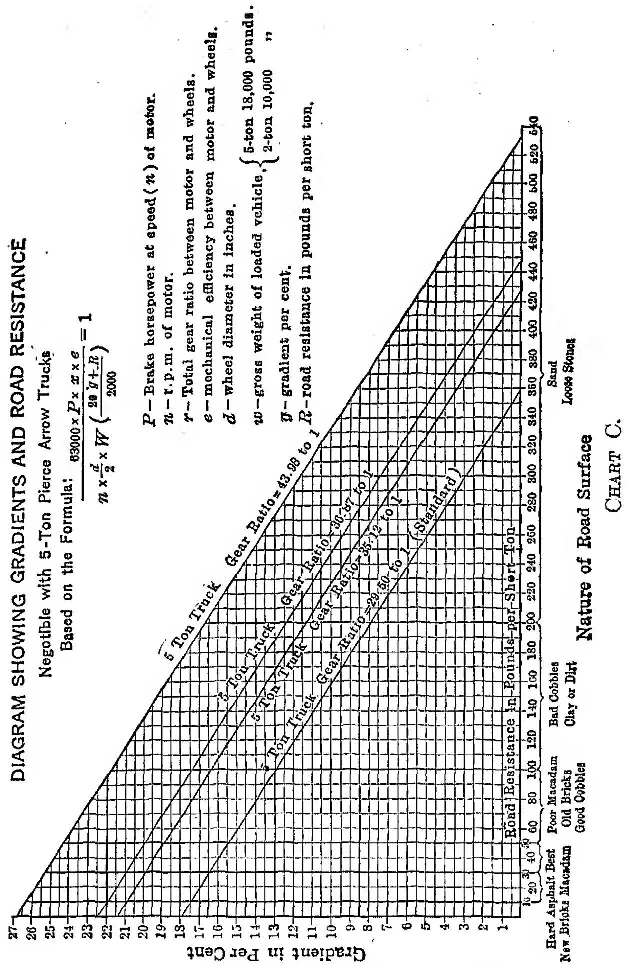
Ascent and Descent.—Light and heavy single unit trucks (trucks without trailers) are commonly operated on firm surfaced roads up and down 15 per cent. grades. Light passenger cars have no difficulty in climbing 15 per cent. grades even on fairly poor natural soil roads. The safety of descent depends largely on the alignment, the condition of the road surface and the brakes but for a well equipped car on safe alignment it is not a noticeable factor in design up to 12 per cent. which is beyond

the reasonable bounds of modern practice in grade selection. *That is, the factors of climbing power and safe descent do not affect the selection of grade from the standpoint of single unit motor transport.* Trailer train motor transport, however, demands low ruling grades. It should, however, be remembered that this type of hauling is comparatively slow. That it increases the danger to ordinary traffic and clutters up the road. That it can not be considered as a probably popular general utility method and that only in rare special cases would we be justified in large expenditures at this time for the purpose of reducing maximum grades below that required for a truck with one trailer in order to increase the train capacity.

Record of Truck Performance.—We are indebted to the Pierce Arrow Motor Car Company for the following chart which shows the ability of their trucks to pull on different kinds of road surfaces and different grades. This data confirms the previous statement that modern trucks have sufficient power to easily handle their full loads on any grade that would be selected for horse traffic on improved roads. (Chart, page 82.)

Convenience of Operation.—Drivers dislike to be forced into second or low gear. If it is possible to approximately determine the rate of grade at which most cars or trucks shift gear this has some bearing on grade selection. It is, of course, difficult to figure this closely as motor design improves, gear ratios vary; cars run on varying degrees of efficiency, gasoline varies in quality, etc., but as a matter of interest the author's experience indicates that the average light pleasure car of the year 1919 shifts into second gear at about 7 per cent. and that very little gear shifting is necessary on long 6 per cent. grades. W. C. Slayton, a truck fleet manager, says that his 5-ton standard gear ratio trucks generally drop into second at about 5 per cent. and that very little shifting would be required on long 4 per cent. grades. Passenger autos drop into low at about 10 per cent. and the 5-ton trucks into low at about 8 per cent.

From the standpoint of convenience in driving pleasure cars these premises, if they apply, indicate that if for any reason a 6 per cent. grade can not be obtained you might just as well use a 10 per cent. and that heavy expenditure to get a 7 per cent. or an 8 per cent. has no bearing on the convenience of the road. This applies only to scenic routes. In the same way for truck hauling if you cannot get a 4 per cent. there is no object from



Optional Gearing on Five-ton Model

The first option is our standard gearing and will be supplied on all orders unless otherwise specified. This gearing should be used where the truck is to traverse good hard roads at all times, and where the grades do not exceed 10 per cent.

The second option gives great pulling power on the low speeds, and the standard speed of 14 miles per hour on high gear. This gearing should be used only where the truck has to pull through a very short portion of poor road and the great majority of the running is done on direct drive. This option is popular with contractors, etc.

The third option is especially suited for districts where by nature of roads

(*Continued at bottom page* 83).

the standpoint of convenience in using less than an 8 per cent. Other factors, however, apply to reduce this extreme jump as discussed later. It should, however, be borne in mind that if trucks are operating regularly over a stated route that special gear ratios can be and are used to meet the existing grades (see Chart C, Note, page 82). *Convenience therefore plays a minor part in grade selection.*

Mechanical Energy Expended on Plus Grades.—*For an equal distance between terminals and an equal rise the mechanical energy expended on a trailer is not greatly affected by the rates of grade. If, however, the selection of rate of grade affects the distance, but not the rise, the lower rate of grade will increase the expenditure of mechanical energy.* To illustrate: Suppose a tractor is hauling a train of farm wagon trailers on a hard surfaced road. The rolling and grade resistance of the trailers per ton of load can be approximated from Table 8, page 76. Suppose there are two villages A and B (see Fig. 20) 10,000 ft. apart and 100 ft. different in elevation.

The theoretical energy in foot-pounds per ton of load to haul the trailers from A to B is for all practical purposes the same for any ordinary maximum grade as shown in Table 9 (page 84).

For traffic going from B to A there is some advantage in the lower rate of grade. Operation costs on minus grades are discussed later.

If we assume that the fuel consumption is proportional to the energy expended, Table 9 indicates that under these conditions for a car climbing *A* to *B* no appreciable saving in fuel consumption results from the use of a low grade. This is not strictly true when applied to a car carrying the motive power generator but it is near enough to help towards a general conclusion. It is probable, however, that the time factor makes the lower grade somewhat cheaper on which to operate (see discussion of time factor, pages 92 to 114). *This adds considerable strength to the contention that very little practical advantage results from reducing grades on local service roads below a reasonable maximum*

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or traffic conditions a high speed is undesirable, or in hilly country, where the road surfaces are good. This gearing is standard equipment on the long wheel base model.

The fourth option should only be used where the road surfaces are exceedingly poor, and the country very hilly. We do not advise using this gearing except in extreme cases.

he distance and rise remain fixed and indicates that the long straight rates of grade in place of a combination of rates does not materially affect the fuel consumption provided otal rise aud fall and distance remains constant.

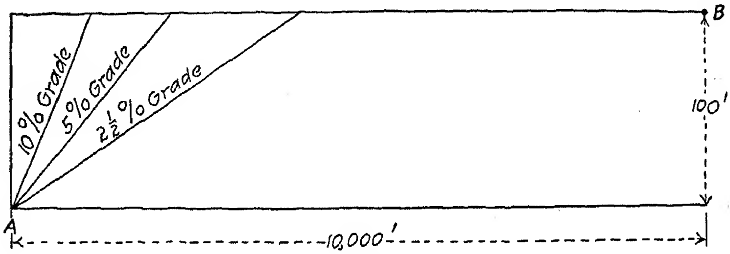


Fig. 20.

Table 9

Rate of grade, per cent.	Resistance per ton of load, in lbs.	Length of grade to rise 100 ft., feet	Foot-lb. of energy to rise 100 ft. on grade shown, ft.-lb.	Remaining distance on level, feet	Ft.-lb. to haul on level for the remaining distance	Total ft.-lb. energy from A to B
2½	90	4,000	360,000	6,000	240,000	600,000
4	120	2,500	300,000	7,500	300,000	600,000
5	140	2,000	280,000	8,000	320,000	600,000
6	160	1,666	266,640	8,334	333,360	600,000
8	200	1,250	250,000	8,750	350,000	600,000
10	240	1,000	240,000	9,000	360,000	600,000
Vertical...	2,000	100	200,000	10,000	400,000	600,000

Resistance per ton of load on level 40 lb.

Now suppose A and B were only 1000 ft. apart in distance and 100 different in elevation. A road between them on a 10 per cent. grade would be only 1000 ft. and would take only 240,000 ft.-lb. of energy per ton of load on the trailer (see Table 9). A road on a 2½ per cent. grade would have to develop additional distance to rise 100 ft. It would be 4000 ft. long and would require 360,000 ft.-lb. of energy to haul 1 ton of load. From this it is possible to see that *where the rise remains fixed and the distance depends on the rate of grade the selection of the lower rate increases the fuel consumption.* Under these conditions it is desirable to use the highest rate of grade that will satisfy the

other requirements of traffic and construction cost such as reasonable limiting loads for teams or trailer trains, convenience in the matter of gear shifts and the cheapest construction location and maintenance cost (see page 116).

Effect of Distance Rise and Time on the Cost of Motor Operation.—A close analysis of this problem is desirable but hardly possible yet. With the great variety of cars, trucks, etc. operating under different degrees of efficiency it is hopeless to arrive at very definite conclusions. General principles based on the laws of mechanics can be derived but actual definite costs are another matter which the author frankly leaves to someone in the future. Long alternate routes can be advantageously compared in value for the elements of distance, rise and time but the value of a close operating cost analysis of grade line design has a very limited application as previously discussed. The time element has not much practical value on short trips as we all waste considerable time during the day anyway but on commercial hauling routes it plays a noticeable part in the cost and for this reason we have analyzed some of the problems in two ways. As a matter of general interest the following approx. data is included. This data has been used by the author personally for some time but merely as a basis for judgment.

Cost of General Operation.—We all have heard the cost of tires, repairs, gas, etc. talked by the hour for the ordinary pleasure car. Each reader probably has his own data but we will assume that the total operating cost on hard surfaced roads in 1919 for the ordinary passenger car including interest on investment, depreciations, insurance, repairs, gas, oil, storage, etc. runs from \$0.05 to \$0.12 per mile. Say \$0.08 average, and that of this gas and oil cost say \$0.02¼, assuming 14 miles per gallon.

We will assume that 5 ton trucks cost about \$28.00 per day to operate. That the total cost of operation will run from \$0.30 to \$0.50 per mile, on improved roads and will probably average about \$0.40 per mile. These trucks get about 3 to 5 miles on a gallon of gas and the cost of fuel will be assumed at \$0.08 per mile.

Two ton trucks under similar service probably cost about \$20.00 per day to operate or about \$0.30 per mile with a fuel cost of say \$0.05 per mile.

It can be seen that the *cost of fuel is only a small percentage of the operation of a truck.*

Value of Distance Saved on Average Grades Provided Rise is not Increased.—Traffic counts, or the general character of territory served by the road in question, can be used as a rough guide as to the probable proportion of horse traffic, passenger cars and trucks.

Taking the ratios of traffic shown in Table, 2 page 69, for the main roads of Massachusetts we get the following average value per vehicle for a saving of 1 mile of distance.

Horse traffic......	6 per cent. of total....	6 × $0.30 per mile =	$ 1.80
Light cars........	87 per cent. of total....	87 × 0.08 per mile =	6.96
Trucks..........	7 per cent. of total....	7 × 0.35 per mile =	2.45
		100	$11.21

$$\frac{\$11.21}{100} = \$0.11 \text{ per mile, say } \$0.10 \text{ per mile for the main roads.}$$

This data agrees with the assumptions of Mr. A. R. Hirst given on page 63. For convenience his tabulation is repeated at this point. This tabulation assumes average going and does not consider various rates of grade. It includes the time factor and is intended for the comparison of long routes or Special Service Commercial Roads. If used as a basis for estimating the value of saving distance on a local service road it is just as well to divide the figures by 2.

Table 10.—Value of a Mile in Highway Distance Saved
(Based on a car mile operating cost of $0.10)

Average Number of Vehicles per Day	Saving to Owners per Year	Saving Capitalized at 5% equals
100	$ 3,650	$ 73,000
250	9,125	182,500
500	18,250	365,000
750	27,375	547,500
1,000	36,500	730,000
2,000	73,000	1,460,000
5,000	182,500	3,650,000
10,000	365,000	7,300,000

Note.—The capitalized value of 1 foot of distance saved for 100 vehicles per day equals $14.

Value of Rise Saved Provided Distance is not Increased and the Time Factor is Ignored.—(Cut and Fill Grading Methods).

The elimination of needless rise and fall between terminals provided the distance is not increased is evidently valuable. There are so many indeterminate factors that we will take refuge in simple theoretical mechanics using the simplest data availabl and then modify the results arbitrarily.

The tabular results given have been used by the author in the absence of reliable data as a rough guide in comparing cut and fill grade reductions for small changes in rise. They do not consider the time factor as it does not have much real practical value for short grade changes. Time is, however, very noticeable on long steep climbs. For comparing total rise and fall on long routes it is better to use Table 11A, page 91, as this considers the time factor. Table 12B, page 104, is perhaps more convenient for general use and has been modified to meet certain practical objections to the more theoretical figures.

Suppose a farm wagon trailer or an automobile is travelling over a hill, Fig. 21.

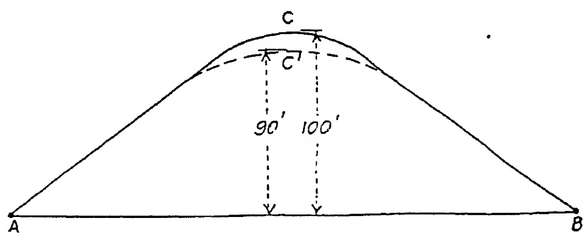


FIG. 21.

If a car started at A from rest and there was no rolling resistance, no air resistance, no friction of any kind, no loss of energy from the engine running while coasting down the grade from C to B or from the application of brakes while descending from C to B, the potential energy of the vehicle at the top of the hill C would be equal to the energy in foot-pounds required to haul it up the hill from A to C and the kinetic energy at B would be the same due to its speed developed by coasting. Under these theoretically perfect conditions no energy is required to move the load from A to B on the level. The energy in foot-pounds per ton of load would be 2000 lb. $\times$ 100 ft. rise = 200,000 ft.-lb. If the car was stopped at B by braking this energy would be lost and the total energy expended would have been 200,000 ft.-lb.

In a similar way the energy expended over the same hill

cut down 10 ft. to C' would have been 2000 lb. $\times$ 90 ft. rise = 180,000 ft.-lb.

The saving in energy resulting from cutting down the hill 10 ft. is 20,000 ft.-lb. or 2000 ft.-lb. per ton of load per foot of rise saved provided the car is stopped at B. In case the car is not stopped at B and the coasting cars partially climb another hill beyond B on their own momentum there is no saving at all accomplished by cutting down the hill shown from C to C' as the car having a kinetic energy of 200,000 ft.-lb. will go farther on its own momentum than the one having a kinetic energy of 180,000 ft.-lb.

The introduction of friction and rolling resistance merely adds a constant loss of energy in the normal grade direction which is practically the same in amount no matter how much the hill is cut down as the difference in the distances ACB, $AC'B$ and AB is not appreciable for ordinary road grades.

As a matter of fact the cars are rarely stopped at the bottom of each hill and it is evident that the saving in expended energy due to grading down a knoll depends on how much of the potential energy at C or C' is lost in descending the grades CB or $C'B$. That is, if half the potential is lost through braking an actual saving of per ton of load of 1000 ft.-lb. of energy results from cutting down the hill 1 ft. If three-fourths of the potential energy is wasted a saving of 1500 ft.-lb. results, etc.

Suppose we carry through a simple case of a farm wagon trailer train starting from rest at A. Full power is applied climbing AC and the energy used per ton of load is (2000 lb. $\times$ total rise in feet) + (rolling resistance in pounds per ton of load $\times$ distance travelled in feet). The potential energy of the train at C per ton of load equals 200,000 ft.-lb. in Fig. 19 and the energy used in overcoming rolling resistance is a dead loss and equals 40 lb. (rolling resistance per ton of load from Table 8) $\times$ distance AC in feet. In a similar way the potential energy at C' equals 180,000 ft.-lb. per ton of load and the energy lost in overcoming the rolling resistance is the same as the first case.

In descending the hill from C to B or C' to B practical wastes of the potential energy occur through keeping the engine running while coasting; through the application of brakes to control the speed on steep grades or through throwing the engine into second or low gear and keeping it engaged to act as a brake. Rolling resistance also eats up its regular supply of energy. On low

grades no shifting of gears occur as a rule nor is the engine thrown out; the driver merely cuts down his gasoline and takes advantage of the gravity help. *That is, there is less potential energy wasted on a light grade than on a heavy grade. This is the principle we wish to develop as it indicates that from a practical standpoint the actual saving in operation cost for eliminating a foot in rise and fall over a hill is less important on light grades than on heavy grades.*

This adds a certain theoretical strength to the contention that for light intermediate grades there is very little advantage to traffic through cutting the top of every knoll and filling every hollow. Prof. I. O. Baker developed this same general principle in the 3rd edition of his book published in 1918.

For purposes of a rough approximation we will assume that 80 per cent. of the potential energy is lost on a 10 per cent. grade; 50 per cent. on a 6 per cent. grade and 10 per cent. on grades of 2 per cent. and less. This is based on Table 8 which shows that on a level the rolling resistance per ton on the level is 40 lb. and that on a 10 per cent. grade the rolling resistance plus gravity = 240 lb. per ton. The down hill gravity pull amounts to 200 lb. per ton. Forty pounds of this is effective in overcoming rolling resistance. We probably lose by brake action 200 − 40 = 160 lb. or $^{160}\!/_{200}$ = 80 per cent. plus engine running waste say 2 per cent. = 82 per cent. This is arbitrarily reduced to 80 per cent. In a similar way the other two values are derived modified by the probability that less brake action and engine loss occur on the 6 per cent. grade. Theoretically no loss occurs on grades of 2 per cent. or less on the basis of a 40 lb. rolling resistance but we have assumed a loss of 10 per cent. as a common sense value. The saving of gas on down grade operation is extremely variable and depends on the regulation of the minimum gas feed and the drivers personal system. These are factors which add uncertainty to any figures.

The theoretical potential energy per foot rise per ton is 2000 ft.-lb. The loss on these grades may therefore be assumed as

10 per cent. grade	80 per cent. loss of 2000 ft.-lb. =	1600 ft.-lb.
6 per cent. grade	50 per cent. loss of 2000 ft.-lb. =	1000 ft.-lb.
2 per cent. grade or less	10 per cent. loss of 2000 ft.-lb. =	200 ft.-lb.

If we assume that the rolling resistance of the farm wagon trailer on a level road is 40 lb. per ton we can convert the saving of energy per foot rise into equivalent distance.

$$\text{ft. rise on 10 per cent. grade} = \frac{1600 \text{ ft.-lb.}}{40 \text{ ft.-lbs.}} = 40.0 \text{ ft. of level distance.}$$

$$\text{1 ft. rise on 6 per cent. grade} = \frac{1000 \text{ ft.-lb.}}{40} = 25.0 \text{ ft. of level distance.}$$

$$\text{1 ft. rise on 2 per cent. grade} = \frac{200}{40} = 5.0 \text{ ft. of level distance.}$$

Assuming an average fuel cost for all classes of traffic on the road at \$ 0.027 per mile on the level the fuel cost per 100 feet of rise per car becomes:

$$\text{On a 10 per cent. grade } \frac{4000}{5280} \times \$0.027 = \$0.02$$

$$\text{On a 6 per cent. grade } \frac{2500}{5280} \times 0.027 = 0.014$$

$$\text{On a 2 per cent. grade } \frac{500}{5280} \times 0.027 = 0.003$$

Using these figures we can compile a table of capitalized value at 5 per cent. for saving 1 ft. of rise without increasing distance. This table has some value as indicating about the extreme expenditure that is justified for the elimination of needless rise and fall by grading down small hills by cut and fill on Local

Table 11.—Capitalized Value of Saving 1 Ft. of Rise and Fall without Increasing Distance

(Based on fuel cost, per mile per car on a level grade, of \$0.027)
(Time factor not considered)

Average no. of vehicles per day	Yearly saving			5 per cent. capitalized value		
	10 per cent. grade	6 per cent. grade	2 per cent. or less	10 per cent. grade	6 per cent. grade	2 per cent.
100	\$ 7.55	\$ 5.10	\$ 1.10	\$ 151	\$ 102	\$ 22
250	18.90	12.75	2.75	378	255	55
500	37.75	25.50	5.50	755	510	110
750	56.65	38.25	8.25	1,133	765	165
1,000	75.50	15.00	11.00	1,510	1,020	220
2,000	151.00	102.00	22.00	3,020	2,040	440
3,000	226.50	153.00	33.00	4,530	3,060	660
4,000	302.00	204.00	44.00	6,040	4,080	880
5,000	377.50	255.00	55.00	7,550	5,100	1,100
10,000	755.00	510.00	110.00	15,100	10,200	2,200

Note.—This table can be used as the extreme basis of cut and fill reductions on local service roads in order to save fuel alone. If we assume that fuel means nothing to 75 per cent. of the traffic divide by 4.

Service roads; it does not consider the time factor of operation as this does not have much practical bearing on minor changes in rise as there is a certain amount of time wasted during the day anyway but this factor becomes very noticeable on long steep climbs and should be considered in comparing long routes, Special Service roads or in making radically different relocations, see Table 11*A* or 12*B*.

TABLE 11*A*.—CAPITALIZED VALUE OF SAVING 1 FT. OF RISE AND FALL WITHOUT INCREASING DISTANCE

(Based on $0.11 per mile per car total operating cost on a +1 per cent. grade)

(Time factor included see pages 92 to 114 for discussion of time factor)

Average no. of vehicles per day	Yearly saving			5 per cent. capitalized yearly saving		
	10 per cent.	6 per cent.	2 per cent. or less	10 per cent.	6 per cent.	2 per cent. grades
100	$ 21	$ 14	$ 3	$ 427	$ 275	$ 30
250	52	35	7	1,067	687	75
500	105	70	15	2,135	1,375	150
750	158	105	23	3,202	2,062	225
1,000	210	140	30	4,270	2,750	300
2,000	420	280	60	8 540	5,500	600
3,000	630	420	90	12,810	8,250	900
4,000	840	560	120	17,080	11,000	1,200
5,000	1,050	700	150	21,350	13,750	1,500
10,000	2,100	1,400	300	42,700	27,500	3,000

NOTE.—This table can be used for the comparison of long routes or indicates about the maximum allowable expenditure for cut and fill reduction on special service commercial roads.

Considering the fact that extra fuel and gas means very little to most road traffic one-fourth of these values would be a liberal expenditure at the present time for such refinements.

Inefficient Operation.—In order not to lose the sense of value of any such figures it is just as well to bear in mind that the American public are not particularly careful of small savings. The average motor car is not kept in a high state of efficiency. If/ the owner himself does not think it worth while to save gasoline by keeping his car in shape how can we expect the community at large to make heavy appropriations for construction

features of design whose value is based on purely theoretical small additional savings. There is undoubtedly more gasoline wasted from careless upkeep and driving than we could ever save by the refinements of the most scientific location and for this reason the author is not inclined to give analyses of this nature much weight except as they indicate general principles, namely: *that the elimination of rise and fall is more valuable on Special Service Commercial roads than on Local Service Roads and of more value on steep than on light grades.*

Distance Balanced Against Rise.—It is even more difficult to analyze such a combination than the simpler cases preceding. At present a definite estimate is not possible. With more data on motor operation a closer approximation will be possible in the future but the great variety of cars, etc. will probably even then tend to weaken the value of the figures. In order to show the effect of the time factor a simple case will be outlined (Fig. 22).

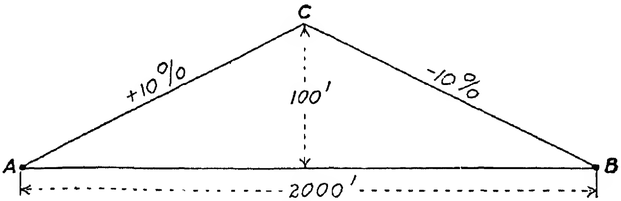


FIG. 22.

Assume two villages A and B 2000 ft. apart separated by a hill 100 ft. high with 10 per cent. grades on both sides. Assume an operating cost of a truck as $24 per ten hour day or $0.04 per minute exclusive of fuel and oil. Assume the fuel cost as $0.08 per mile operating on the level. Assume a rolling resistance of 40 lb. per ton on the level.

Under these assumptions if the truck starts from A and stops at B coasting down grade from C to B and stopping at B, the energy expended per ton of load would be approximately (1000 ft. distance × 240 lb. pull) + (an allowance for the engine running free from C to B, say 10 per cent. of energy required for running 1000 ft. on the level or 10 per cent. of 40,000 ft.-lb.) = 244,000 ft.-lb.

The amount of energy required per ton of load from A to B on the level would be 2000 ft. distance × 40 lb. pull — 80,000 ft.-lb. Assuming that the fuel expenditure is directly pro-

portional to the expenditure of energy the fuel consumption over the hill would be $\frac{244,000}{80,000} = 3$ times as great as on the level or in money at \$0.08 per mile on the level it would be $\frac{2000}{5280} \times$ \$0.08 $\times$ 3 = \$0.09. The fuel consumption on level = \$0.03.

Suppose we consider the time factor. Assume that the maximum speed on the level is regulated by law to 12 miles per hour. The time consumed to go 2000 on the level is approximately 2 minutes which amounts in money at \$24 per day to approximately \$0.08. Suppose the truck makes 3 miles per hour in low gear travelling from A to C and 8 miles per hour coasting down hill from C to B. The time over the hill would be approximately 5 minutes or in money \$0.20.

The total operating cost over the hill would be approximately \$0.29 and on the level \$0.11 or a difference of \$0.18.

If these assumptions were correct we could afford to increase the length of the road to 5300 ft. on the level or 2½ times as

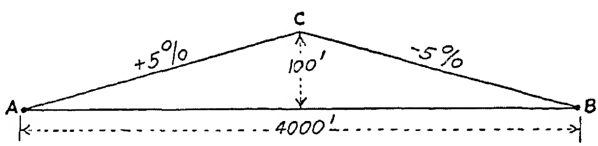


FIG. 23.

far to avoid the hill as far as the operating cost of the truck is concerned. These assumptions are not necessarily correct but in the absence of more reliable data the author would have no hesitation in increasing the distance by from 2 to 2½ times for truck traffic based on such an analysis. The cost of construction of the two routes would of course be balanced against the operating cost.

Take the same case for the two villages A and B 4000 ft. apart on 5 per cent. grades.

The energy over the hill per ton of load is assumed as (2000 $\times$ 140) + (10 per cent. of 2000 $\times$ 40) = 288,000 ft.-lb.

The energy on the level = 160,000 ft.-lb.

Fuel consumption over the hill = \$0.11

Fuel consumption on level = \$0.06

The speed climbing the 5 per cent. grade would probably be about 6 miles per hour and about 12 miles per hour coasting down

the hill provided the alignment is good as the extreme control necessary on a 10 per cent. grade is not required.

The time over the hill becomes approximately................	5 minutes
The time on the level becomes approximately.................	4 minutes
The time cost over the hill approximately...................	$0.20
The time cost on the level approximately....................	0.16
Total cost over hill..	0.31
Total cost on level...	0.22

In this case we could afford to increase the distance 40 per cent. to get a level road from the standpoint of truck operating cost. Light motors would not justify any such increase as later discussed.

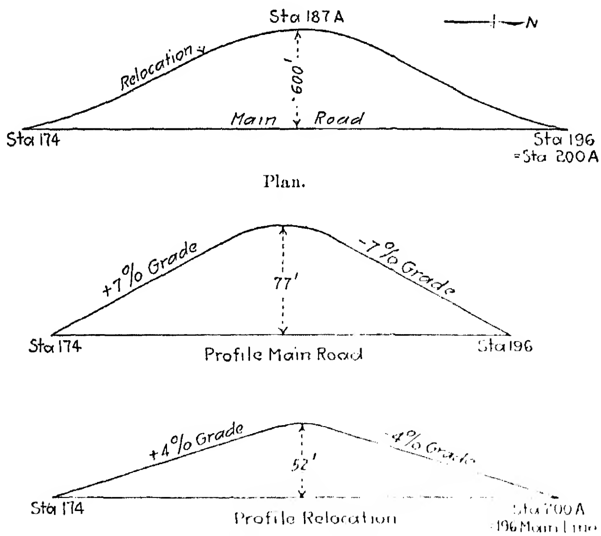


FIG. 24.—Pugsley hill relocation.

As discussed on page 89 the value of the reduction of rise and fall decreases as the rate of grade decreases so that while in extreme cases it is desirable to increase distance to eliminate rise this expedient must be used with care for light grades and small hills for *as a rule short distance outweighs minor intermediate rise and fall.*

To give a theoretical application of such figures to a definite case we will cite a concrete example known as the Pugsley Hill relocation of the Mendon-Pittsford Road in New York State (see Fig. 24).

The main straight road goes over the top of a high hill; the natural saddle is located about 600 ft. west of the main road and is 25 ft. lower than the summit on the main road. The main road used a 7 per cent. cut and fill grade reduction and the relocation a 4 per cent. balanced side hill location. The snow conditions are much better on the new location, the cost of construction is less and the rise less. Suppose we make a rough comparison of the cost of operating over the two locations.

Cost of Operating over Main Line (Trucks)

Fuel $\dfrac{(180 \times 1{,}100) + (10 \text{ per cent. of } 44{,}000 \text{ ft.-lb.})}{212{,}000 \text{ ft.-lb. per mile on level}} \times$ \$0.08 per mile on level. . . . = \$0.08

Time Average 6 miles per hour \$0.04 per min. (assumed) = 0.16

Total cost. . . . \$0.24

Cost of Operating over New Line (Trucks)

Fuel $\dfrac{(120 \times 1{,}300) + (10 \text{ per cent. of } 52{,}000)}{212{,}000} \times 0.08$ = \$0.06

Time Average 10 miles per hour (assumed) = 0.12

Total cost. . . . \$0.18

That is we have enough data to conclude that the operating cost on the new line is slightly less than the Old Main Road. This data does not however warrant our putting a money value on this difference as there are too many unknown factors, particularly that of time. Purely as a matter of academic interest we can carry this example a little further. This road carries today a traffic of approximately 950 motor cars and 80 trucks per day in summer. It is safe to assume that this amount of traffic applied for 250 days per year will about represent the total yearly traffic. If we assume that the pleasure cars cost about 1/7 as much to operate as the trucks we can arrive at a rough guess of the yearly saving \$3000. This capitalized at 5 per cent. would amount to \$60,000 which represents theoretically the additional amount we would be justified in spending to get the new location.

As a matter of practical interest we will say that despite the advantages of an apparently lower operating cost, less snow trouble and lower construction cost this new line was not built on account of the difficulty of acquiring right of way. The farmer wanted \$5000 for 3 1/2 acres on account of cutting up his

property. It was undoubtedly poor policy to let this stand in the way and it is probably only a question of time before the relocation will be made as this hill controls the maximum grade on a through State Route.

Comparison of Distance and Rise.—For quick rough comparisons of such relocations we can compile a table which in the absence of really reliable data will serve the purpose. Table 12A approximates the theoretical relation. Table 12B is compiled from a practical standpoint.

We will compute the approximate comparative cost of operating on different rates of grade which are close enough to give some basis for judgment on the relative value of two locations from the standpoint of motor operation. Table 12A gives full value to the time factor. Table 12B modifies the fuel and time factor.

Table 12A is made on the basis of $0.11 average motor operation on a +1 per cent. grade. This is considered a reasonable cost for the proportions of Truck, Car and Horse traffic shown in Table 2, page 69. It is assumed that the road alignment is fairly good; for the effect of dangerous alignment see page 141. We will assume that the speed is reduced to ½ normal at +5 per cent. and to ¼ normal at +10 per cent. grade; that the speed says at normal on the level and remains normal on down grades to −5 per cent. and that after this rate of grade is passed that it is reduced to ½ normal at −10 per cent. grade. We will assume an average fuel cost per mile on the +1 per cent. grade of $0.03 and that the fuel consumption is directly proportional to the theoretical energy expended climbing. We will make some arbitrary allowances on down grades. We will assume a theoretical draw bar pull of 40 lb. per ton on the level. The down grade fuel consumption varies with each driver and car. It depends on the minimum gas feed adjustment of the throttle and whether the clutch is thrown out and the engine stopped or run free; or whether the engine is used as a brake and various other factors. The values used by the author have been criticised but the suggestions received raise some factors or lower others and the net result agrees closely with the tabulation. The object of this analysis is to make a start towards some reasonable basis for judgment and if the reader believes he has better data it is very simple to make up a table similar to No. 12 to 12*B* for use under his conditions.

On this basis the cost of operation per mile on the different grades is as follows:

Level	\$0.107	Level	\$0.107
+ 1 per cent	0.110	− 1 per cent	0.104
+ 2 per cent	0.126	− 2 per cent	0.098
+ 3 per cent	0.148	− 3 per cent	0.092
+ 4 per cent	0.176	− 4 per cent	0.086
+ 5 per cent	0.210	− 5 per cent	0.083
+ 6 per cent	0.244	− 6 per cent	0.095
+ 7 per cent	0.278	− 7 per cent	0.107
+ 8 per cent	0.312	− 8 per cent	0.119
+ 9 per cent	0.346	− 9 per cent	0.131
+10 per cent	0.380	−10 per cent	0.143

These costs were derived as follows. The operating cost of \$0.11 per mile on a + 1 per cent. grade was apportioned as given below:

		Remarks
Fuel	\$0.03	Variable fuel factor.
Tires	0.015	Constant distance factor.
Repairs	0.01	¼ Distance, ¾ time factor.
Driver's time	0.015	Time factor.
Depreciation	0.02	¼ Distance, ¾ time factor.
Interest on investment, insurance, garage, license, etc.	0.02	Time factor.
	\$0.11	

To determine the operating cost on any other grade we have used 3 factors. The constant distance factor made up of tires, ¼ of the repairs and ¼ of the depreciation. The variable fuel factor and the variable time factor made up of driver's time, interest, ¾ of the depreciation and ¾ of the repairs. This time factor is the largest factor. It depends on the speed of the operation and is largely a matter of judgment until we have more and better information.

The data given is based on the author's best judgment in assigning arbitrary values to these factors and ratios on different grades.

Time cost on a +1 per cent. grade	\$0.06 per mile
Fuel cost on a +1 per cent. grade	0.03 per mile
Distance factor cost (constant)	0.02 per mile
Total	\$0.11

7

Analysis of Relative Operating Cost of Average Motor Traffic for 1 Mile of Distance on Different Rates of Grade, Based on $0.11 per Mile on a 1 Per Cent. Grade

Distance factor $0.02 for 1 per cent. grade			Fuel factor $0.03 for 1 per cent. grade		Time factor $0.06 for 1 per cent. grade		Total operating cost
Rate grade per cent.	Factor ratio for each rate of grade	Cost for each grade	Factor ratio for each rate of grade	Cost for each grade	Factor ratio	Cost for each grade	
+10	1	$0.02	4	$0.12	4.0	$0.24	0.380
+ 9	1	0.02	$3\frac{2}{3}$	0.11	3.6	0.216	0.346
+ 8	1	9.02	$3\frac{1}{3}$	0.10	3.2	0.192	0.312
+ 7	1	0.02	3.0	0.09	2.8	0.168	0.278
+ 6	1	0.02	$2\frac{2}{3}$	0.08	2.4	0.144	0.244
+ 5	1	0.02	$2\frac{1}{3}$	0.07	2.0	0.120	0.210
+ 4	1	0.02	2.0	0.06	1.6	0.096	0.176
+ 3	1	0.02	$1\frac{2}{3}$	0.05	1.3	0.078	0.148
+ 2	1	0.02	$1\frac{1}{3}$	0.04	1.1	0.066	0.126
+ 1	1	0.02	1.0	0.03	1.0	0.06	0.110
Level	1	0.02	0.9	0.027	1.0	0.06	0.107
	1	0.02	0.8	0.024	1.0	0.06	0.104
2	1	0.02	0.6	0.018	1.0	0.06	0.098
− 3	1	0.02	0.4	0.012	1.0	0.06	0.092
− 4	1	0.02	0.2	0.006	1.0	0.06	0.086
− 5	1	0.02	0.1	0.003	1.0	0.06	0.083
− 6	1	0.02	0.1	0.003	1.2	0.072	0.095
− 7	1	0.02	0.1	0.003	1.4	0.084	0.107
− 8	1	0.02	0.1	0.003	1.6	0.096	0.119
− 9	1	0.02	0.1	0.003	1.8	0.108	0.131
−10	1	0.02	0.1	0.003	2.0	0.120	0.143

Note 1.—If anything the fuel factor between the grades of −3 per cent. and −10 per cent. is a trifle low.

Note 2.—The time factor between the rates of grade of −5 per cent. and −10 per cent. depends very largely on the alignment, the individual driver and whether or not he is in the habit of driving on steep grades. It is probably about right for passenger cars but too high for truck operation and might be reduced to 1.5 at a −10 per cent. for truck traffic in hilly country.

Note 3.—The time factor on grades of +2 per cent. to +10 per cent. is too high for high power touring cars as on good alignment the normal speed is often not reduced at all up to 6 per cent.

Table 12.—Table of Approximate Capitalized Cost at 5 Per Cent. of Yearly Operating 100 Average Motor Cars Daily for 365 Days per Year for 1 Foot Distance on the Various Grades

(Time factor considered)
(Based on car mile operating cost of $0.11 on average grades)
(Aligment assumed to be good)

Rate of grade per cent.	Yearly operation 100 cars daily (36,500 cars yearly)	Capitalized yearly operation cost	Rate, per cent.	Yearly	Capitalized
Level	$0.74	$14.80	Level	$0.74	$14.80
+ 1	0.76	15.20	− 1	0.72	14.40
+ 2	0.87	17.40	− 2	0.67	13.50
+ 3	1.02	20.40	− 3	0.63	12.70
+ 4	1.22	24.40	− 4	0.60	11.90
+ 5	1.45	29.10	− 5	0.57	11.50
+ 6	1.68	33.70	− 6	0.66	13.10
+ 7	1.92	38.40	− 7	0.74	14.80
+ 8	2.16	43.20	− 8	0.82	16.50
+ 9	2.39	47.80	− 9	0.90	18.10
+10	2.62	52.50	−10	0.99	19.80

Note.—*This table to be used only for general comparisons of the relative value of routes or alternate locations. The actual costs given are of very little value.* The figures are based on an average operating cost for all classes of travel at $0.11 per mile on a +1 per cent. grade.

If a car climbs a grade going in one direction it will descend the same grade going in the opposite direction so that table 12 can be simplified for purposes of comparing Routes, Alternate Locations and Alternate Cut and Fill profiles by averaging the plus and minus grades of the same rate. Table 12A is compiled on this basis modified slightly to produce a smooth graph. In order to illustrate the relative value of light grades for Truck Traffic and Light Motor traffic columns 2 & 3 of table 12A have been compiled modifying the time factor according to the foot notes of the operating cost analysis given on page 98. These relations are shown by a rough graph, page 101.

Examples of the Use and Limitations of Table 12A.—The main value of this table lies in the indication of general principles. It also affords a quick method of comparison of the value of long alternate routes and locations from the standpoint of motor operation costs. It has a limited use for the comparison of the relative value of alternate cut and fill grade line designs from the

standpoint of motor operation but for comparisons of this kind Table 12B has more real value. The actual costs given are based on personal judgment and must be used with caution. The relative costs have a well defined value.

TABLE 12A.—APPROXIMATE CAPITALIZED COST AT 5 PER CENT. OF OPERATING 100 MOTOR VEHICLES DAILY (36,500 PER YEAR) FOR 1 FOOT OF DISTANCE ON THE VARIOUS GRADES

(Time factor included)

Rate of grade per cent.	Column 1 Average Traffic Trucks & light vehicles Based on $0.11 per mile average grades	Column 2 Light Motor vehicles Based on $0.08 per mile average grades	Column 3 heavy commercial trucks Based on $0.40 per mile average grades
Level	$14.80	$10.70	$54.00
1	14.80	10.75	54.00
2	15.10	10.85	54.60
3	16.10	11.05	56.70
4	17.90	11.40	63.90
5	20.50	12.00	74.10
6	23.30	12.90	84.50
7	26.40	14.50	95.00
8	29.60	16.15	105.60
9	32.80	17.90	116.20
10	36.00	19.70	127.00

NOTE.—This table to be used only for rough general comparisons of the relative value of alternate long routes. The actual costs must be used with caution. Alignment good. For effect of dangerous alignment see page 141.

An examination of the graph curves indicates that light car traffic is not as much affected by rate of grade as heavy truck traffic. This is borne out by even casual observation and common sense. The light car curve runs practically level from the level rate of grade to 5 per cent. rate and steepens up sharply between 5 and 7 per cent. grades. This indicates that for this class of traffic there is very little practical value in the reduction of natural profile grades by cut and fill up to a 6 per cent. grade. Theoretically the graph indicates a saving in operation costs for reductions to about a 2 per cent. rate but this would be an *excessive refinement* at the present stage of highway programs

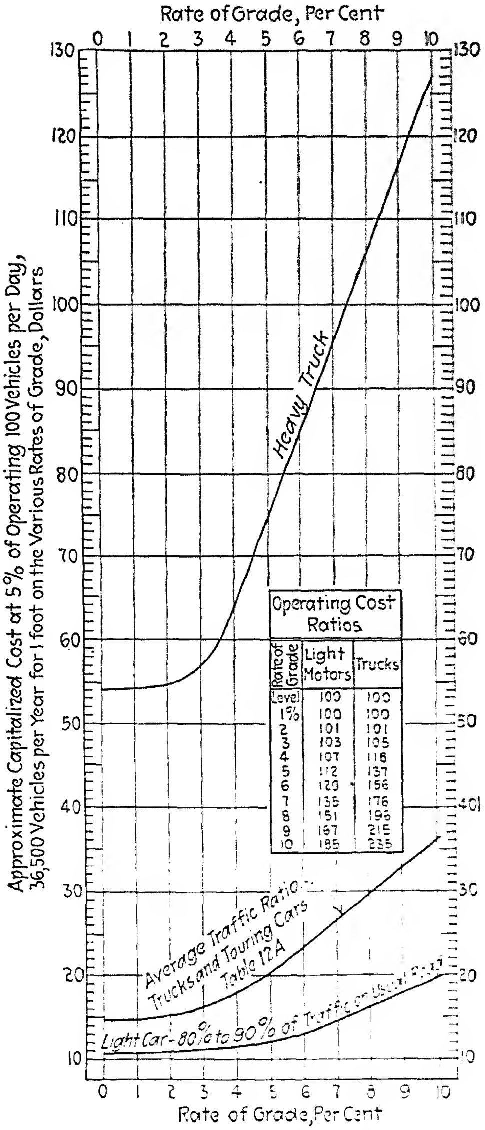


FIG. 25.—Graph of table 12A, showing the relative effect of grade on truck and pleasure car traffic (time factor included). This graph assumes that the alignment is fairly good. For the effect of dangerous alignment see page 141.

This graph assumes that ½ the travel is up hill and ½ down hill.

and it is rarely economical considering the relative cost of construction and operation unless the time factor is considered a real factor. In a similar way for Commercial Truck Traffic there is very little practical advantage in reducing the average intermediate grades by cut and fill below 4 per cent. A reduction to 2 per cent. is desirable if it can be accomplished without excessive grading but any such reduction is as a rule not justified except in flat country.

The practical value of Table 12A and its limitations in solving problems can be illustrated as follows:

Comparison of Alternate Locations

To illustrate the use of Table 12A for such comparisons we will apply it to the two locations over Pugsley Hill given on page 94.

Capitalized Cost of Operation for 100 Vehicles per Day

(Average traffic)

.ine, 2200 ft. on 7 per cent. grade @ $26.40	= $58,080
.tion, 2600 ft. on 4 per cent. grade @ 17.90	= 46,540
Approximate value of Relocation for 100 vehicles per day	= $11,540

(Assuming that time and gasolene means something to every user)

Capitalized Cost of Operation (Light Cars 100 Daily)

Main line, 2200 ft. on 7 per cent. grade @ $14.50	= $31,900
Relocation, 2600 ft. on 4 per cent. grade @ 11.40	= 29,640
Approximate value of relocation (100 cars daily)	= $ 2,260

(Assuming that time and gas mean something to all these cars)

Capitalized Cost Operation (Heavy Trucks 100 Daily)

Main line, 2200 ft. on 7 per cent. grade @ $95.00	= $209,000
Relocations, 2600 ft. on 4 per cent. @ 63.90	= $166,140
	$ 42,860

Comparison of the two lines from the standpoint of the expenditure of Mechanical energy climbing

1100 lin. ft. × 180 lb. pull per ton = 198,000 ft.-lb. per ton
1300 lin. ft. × 120 lb. pull per ton = 156,000 ft.-lb. per ton

All the methods shown an advantage for the relocation.

This road is a State Route carrying approximately 650 motors per day of which approx. 10 to 15 per cent. are trucks of over two ton capacity.

Using the average traffic curve the relocation might possibly be worth theoretically 6.50 × \$11,540 = \$75,000 provided we assume that gas and time means something to all the traffic. Common sense would, however, forbid any such expenditure on this particular line. As a matter of fact the light motor traffic would not be particularly benefited as the theoretical saving in operation cost is not over 7 per cent. The actual time and depreciation saving if any exists is so small that it means nothing to this class of traffic. That is, the average light motor would just as soon operate over the hill on a 7 per cent. as to make a short detour to get a 4 per cent. We can therefore eliminate light traffic operation cost as a factor in the decision. The truck traffic is probably actually benefited by the relocation. Theoretically the relocation reduces the operating cost about 20 per cent. Some of these trucks are local service trucks and the small time saving is of no consequence. Perhaps 50 per cent. of trucks get the full theoretical benefit which might justify an expenditure of \$20,000 for 100 trucks or for this particular road carrying about 80 trucks daily a total additional expenditure of from \$15,000 to \$20,000. It should be borne in mind, however, that the truck traffic is a small percentage of the total traffic. It is not at all likely that the community at large would favor any such expenditure for the favored few if they knew what was going on and it is not likely that if the proposition was put up to the truck owners that they would be willing to plank down \$20,000 for the work.

The argument for this location therefore boils down to the facts that while we know that the relocation is the better line from the standpoint of operation we would hesitate to spend much additional at this time as the road program is financed by a general tax and the direct return to the community at large is too intangible. If we were working on a reconstruction program financed by motor license fees of which the truck owners paid a reasonable proportion of the cost there would be no hesitation in building the line as it could be done for a sum well within the amount saved.

The use of Table 12A may not warrant placing a money value on the saving in operating cost but it certainly justifies the conclusion that the relocation is the better line from the standpoint of motor operation. If such a relocation improves snow conditions, increases the convenience by preventing gear shifts, reduces the

f maximum grade for a long road and can be built for less he old road location, which was the case in this instance, most certainly justified.

ctical Basis of Comparison of Short Alternate Locations ut and Fill Profiles.—For the benefit of the younger men, 12B has been compiled to serve as a basis for arriving at treme expenditure justified by savings in operation costs relocations and grading at this time 1920. Bearing in the approximate nature of such figures, no change in loca- profile design should be made unless the saving in opera- ost is distinctly larger than the increase in construction A ratio or at least 2 to 1 is recommended.

umn 1 applies to Local Service Roads and Secondary State s carrying up to approximately 1800 vehicles per day.

12B.—Approximate Capitalized Cost at 5 Per Cent. of Oper- 100 Motor Vehicles Daily (36,500 per Year) for 1 Ft. of Distance on the Various Grades

ime factor modified Columns 1 & 2. Fuel cost not con- or 50 per cent. of light motors Columns 1 & 2.

of grade cent.	Column 1. Local service roads and secondary state routes	Column 2. Main inter-city state roads Probable future traffic 1800 or more	Column 3. Future commercial truck toll roads
evel	$ 9.10	$12.20	$54.00
1	9.10	12.20	54.00
2	9.15	12.30	54.60
3	9.25	12.50	56.70
4	9.40	12.80	63.90
5	9.70	13.50	74.10
6	10.20	14.50	84.50
7	11.20	15.80	95.00
8	12.50	17.70	105.60
9	14.00	19.80	116.20
10	15.50	22.00	127.00

.—As a general rule make no changes in existing locations or grade hich fit the natural surface unless the saving in approximate operat- is at least twice the additional cost of construction. This note does ly to changes which are desirable to improve the safety or con- of the road.

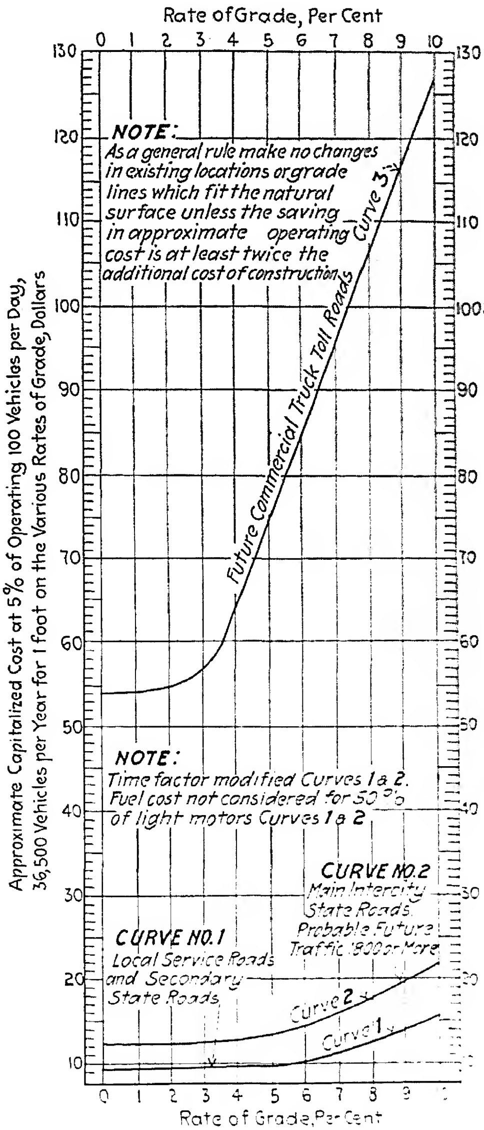


FIG. 26.—Graph of table 12B. A practical basis of comparison. This graph assumes that the alignment is fairly good. (see also page 141.)
This graph assumes that ½ the travel is up hill and ½ down hill.

Column 2 applies to Main inter-city Routes. Column 3 indicates possible expenditures, sometime in the future, for Special Truck hauling roads constructed and maintained by a direct tax or toll on the trucks using the road.

Examples of the Value and Limitations of Table 12B.—These examples are included as much to show various practical considerations in grade line designing as they are to illustrate the general value of Table 12B. No rules or standards can be used without judgment.

Case I. Comparison of Short Alternate Locations (Distance Balanced Against Rise)

Use the Pugsley Hill relocation described on page 94. A practical comparison of value of the two lines is not entirely based on the relative operating and construction costs.

Suppose we compare this relocation assuming that this road might be either a Local Service Road carrying 500 motors per day; a State Inter-city Route carrying 2000 motors per day or a Future Commercial Truck Road carrying 2000 trucks per day.

Use Table 12B, columns 1, 2 and 3.

Local Service Classification

Existing road location, 2200 ft. on 7 per cent. grade @ $11.20	=	$24,640
New location, 2600 ft. on 4 per cent. grade @ 9.40	=	24,440
Approx. advantage of Relocation per 100 vehicles	=	200
Total advantage for this case, 5 × $200	=	$ 1,000

From the standpoint of operating cost this relocation can be assumed to warrant an additional expenditure of $\frac{1000}{2} = \$500$. For a local service road the saving in operation cost is negligible (not over 1 per cent.). As a matter of fact the approximate nature of the figures makes it doubtful if there is any saving. As previously stated page 103 the relocation was warranted by improvements in snow conditions, reduction of maximum grade for a long road and a reduction in construction cost.

Inter-city Road Classification

Existing location, 2200 ft. on 7 per cent. grade @ $15.80	=	$34,760
Relocation, 2600 ft. on 4 per cent. grade @ 12.80	=	33,280
Approximate value Relocation per 100 motors	=	1,480
Total advantage for this case, 20 × $1480	=	29,600

Allowable expenditure $\frac{\$30000}{2} = \$15,000$

Under these conditions the relocation is desirable.

FUTURE TRUCK ROAD CLASSIFICATION

(Construction financed by road users)

Existing location,	2200 ft. on 7 per cent.	@ $95.00	=	$209,000
Relocation,	2600 ft. on 4 per cent.	@ 63.90		166,140
Approximate value of relocation 100 trucks			=	43,000
Total advantage for this case, 20 × $43,000			=	860,000
Approximate allowable expenditure = $500,000.				

For a road of this character the relocation would not only be justified but a further reduction to a 2 per cent. grade by cut and fill could probably be made at a cost of only a fraction of $500,000.

Comparison of Cut and Fill Grade Line Profiles.—In comparing all alternate cut and fill grade lines it is assumed that the road is well located or that it is fixed for some practical reason by existing rights of way.

CASE I. COMPARISON OF THE USE OF A REASONABLE MAXIMUM GRADE AND A REDUCTION IN TOTAL RISE WITH A LOWER RATE OF GRADE AND NO REDUCTION IN RISE. (DISTANCE FIXED)

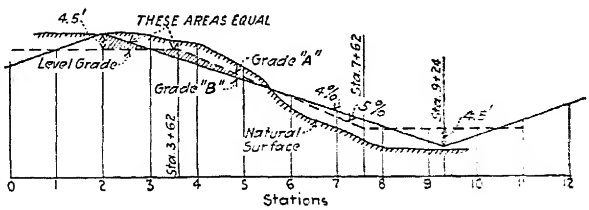


FIG. 27.

Grade line "A" uses a 5 per cent. maximum and decreases the height of the hill 9 feet.

Grade line "B" uses a 4 per cent. rate and does not reduce the height of the hill.

The Amount of Excavation is the Same for Both Lines.—For a given expenditure of money in rolling topography is it better to use a reasonable maximum and reduce rise or use a lower rate of grade and fail to reduce rise?

Suppose we compare this line first from the standpoint of the mechanical energy required for climbing from Sta. 9 + 24 to 2 + 00.

Column 2 applies to Main inter-city Routes. Column 3 indicates possible expenditures, sometime in the future, for Special Truck hauling roads constructed and maintained by a direct tax or toll on the trucks using the road.

Examples of the Value and Limitations of Table 12B.—These examples are included as much to show various practical considerations in grade line designing as they are to illustrate the general value of Table 12B. No rules or standards can be used without judgment.

CASE I. COMPARISON OF SHORT ALTERNATE LOCATIONS (DISTANCE BALANCED AGAINST RISE)

Use the Pugsley Hill relocation described on page 94. A practical comparison of value of the two lines is not entirely based on the relative operating and construction costs.

Suppose we compare this relocation assuming that this road might be either a Local Service Road carrying 500 motors per day; a State Inter-city Route carrying 2000 motors per day or a Future Commercial Truck Road carrying 2000 trucks per day.

Use Table 12B, columns 1, 2 and 3.

LOCAL SERVICE CLASSIFICATION

Existing road location,	2200 ft. on 7 per cent. grade @	$11.20	= $24,640
New location,	2600 ft. on 4 per cent. grade @	9.40	= 24,440
Approx. advantage of Relocation per 100 vehicles			= 200
Total advantage for this case, 5 × $200			=$ 1,000

From the standpoint of operating cost this relocation can be assumed to warrant an additional expenditure of $\frac{1000}{2} = \$500$. For a local service road the saving in operation cost is negligible (not over 1 per cent.). As a matter of fact the approximate nature of the figures makes it doubtful if there is any saving. As previously stated page 103 the relocation was warranted by improvements in snow conditions, reduction of maximum grade for a long road and a reduction in construction cost.

INTER-CITY ROAD CLASSIFICATION

Existing location,	2200 ft. on 7 per cent. grade @	$15.80	= $34,760
Relocation,	2600 ft. on 4 per cent. grade @	12.80	= 33,280
Approximate value Relocation per 100 motors			= 1,480
Total advantage for this case, 20 × $1480			= 29,600

Allowable expenditure $\frac{\$30000}{2} = \$15,000$

Under these conditions the relocation is desirable.

FUTURE TRUCK ROAD CLASSIFICATION

(Construction financed by road users)

Existing location,	2200 ft. on 7 per cent.	@	\$95.00	=	\$209,000
Relocation,	2600 ft. on 4 per cent.	@	63.90		166,140
Approximate value of relocation 100 trucks				=	43,000
Total advantage for this case, 20 × \$43,000				=	860,000
Approximate allowable expenditure = \$500,000.					

For a road of this character the relocation would not only be justified but a further reduction to a 2 per cent. grade by cut and fill could probably be made at a cost of only a fraction of \$500,000.

Comparison of Cut and Fill Grade Line Profiles.—In comparing all alternate cut and fill grade lines it is assumed that the road is well located or that it is fixed for some practical reason by existing rights of way.

CASE I. COMPARISON OF THE USE OF A REASONABLE MAXIMUM GRADE AND A REDUCTION IN TOTAL RISE WITH A LOWER RATE OF GRADE AND NO REDUCTION IN RISE. (DISTANCE FIXED)

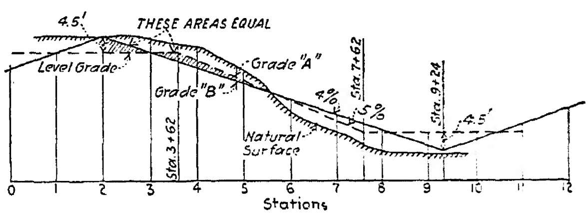


FIG. 27.

Grade line "A" uses a 5 per cent. maximum and decreases the height of the hill 9 feet.

Grade line "B" uses a 4 per cent. rate and does not reduce the height of the hill.

The Amount of Excavation is the Same for Both Lines.—For a given expenditure of money in rolling topography is it better to use a reasonable maximum and reduce rise or use a lower rate of grade and fail to reduce rise?

Suppose we compare this line first from the standpoint of the mechanical energy required for climbing from Sta. 9 + 24 to 2 + 00.

ENERGY EXPENDED

Grade Line A		
400 ft. on 5 per cent. Grade @ 140 lb. per ton	=	56,000 ft.-lb.
324 ft. on Level @ 40 lb. per ton	=	12,960 ft.-lb.
Total	=	68,960 ft.-lb.
Grade Line B		
724 ft. on 4 per cent. Grade @ 120 lb.	=	86,880 ft.-lb.

The expenditure of energy on the down grade is indefinite and is due very largely to the driver. He may coast and let his engine run free or use the minimum gasolene and use the engine as a break. The chances are that he will use slightly less on Grade B than on Grade A but not enough less to balance the advantage of Grade A on the climb. The probabilities are all in favor of the supposition that Grade A is the best grade on the score of fuel consumption.

Now suppose we use Table 12B to compare these two lines. This table considers the indefinite items of down grade operation and wear and tear on the car.

Compare the operating cost on these two profiles. Use column I Table 12B. *Local Service Roads.*

Grade "B"	724 ft. on 4 per cent. grade @ $9.40	=	$6805
Grade "A"	400 ft. on 5 per cent. grade @ $9.70 324 ft. on Level @ 9.10	=	6828

These figures indicate that for all practical purposes the cost of operation is the same for either Grade A or Grade B, and that either could properly be used depending on which fitted the topographical conditions best. The author believes this is a sound conclusion.

On local service roads the evidence is slightly in favor of grade line *A* and as time and car depreciation have less real value than on Commercial Roads. It is assumed that this hill does not control the maximum grade and that 5 per cent. is reasonable for this road. Even on Commercial roads it would probably be better to use grade line A if this hill did not control the maximum grade but if it did control the maximum grade there is absolutely no question but that grade line B is the better design.

CASE II. TO COMPARE DIFFERENT DEPTHS OF CUTTING THROUGH THE TOP OF A HILL

The profile of the Scottsville-West Henrietta Road shown, is a portion of a road now under contract. The maximum grade on

this road is 7 per cent. The two 5 per cent. grades and vertical curve marked "A" show the plan grade.

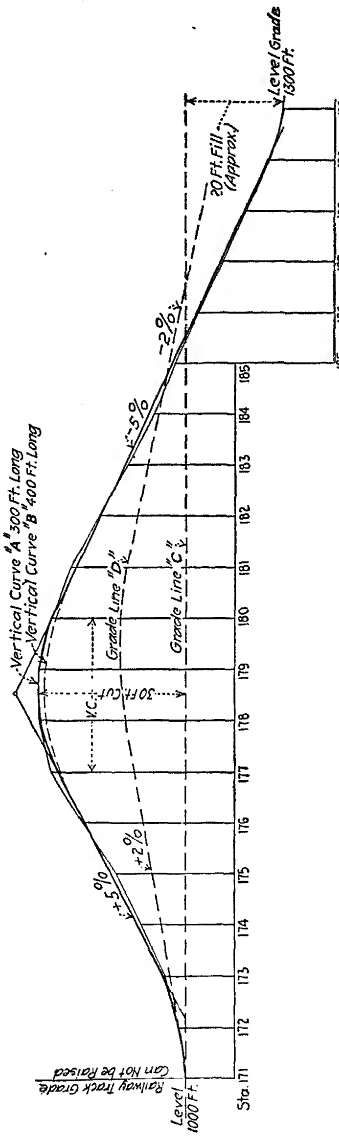


FIG. 28.—Profile of Scottsville, W. Henrietta road.

The question is whether it is desirable from the standpoint of operating cost to cut this hill any farther by grade line "B" and

how much of a cut is justified according to Table 12B. This road is a local service road carrying approximately 250 motors per day. It is a crossroad in the system shown in Fig. 13, page 41 and its improvement will not probably increase the traffic to over 400 rigs per day.

Vertical curve "A" has a length of 300 feet. Suppose we try a 400 foot vertical curve; this would cut down the hill approximately 1.25 feet below Curve "A." The relative cost of operating over grade "A" and grade "B" from station 176 to 181 by Table 12B is as follows (Column I).

Grade line "A"	200 ft. on 5 per cent. grade	@ \$9.70	= \$4700
	300 ft. on 2½ per cent. average	@ 9.20	
Grade line "B"	100 ft. on 5 per cent. grade	@ 9.70	= \$4650
	400 ft. on 2½ per cent.	@ 9.20	

Approximate advantage line "B" for 100 motors per day = \$ 50

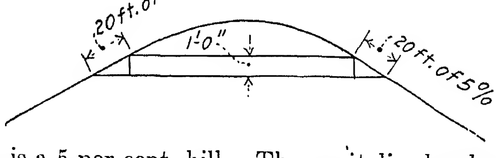
Total advantage, 4 × \$50 = \$200

Approximate allowable expenditure $= \dfrac{200}{2} = \$100$

The excavation taken from the top of the hill will not affect the height of the grade Station 190 and 203 so that the cut of 1.25 feet represents the full value of this work.

The extra cost of grade line "B" over grade line "A" would be about \$350 which indicates that the plan grade should not be lowered. If this road carried 1500 motors per day we might be justified in grade line "B" from the standpoint of operation cost but practically it would probably not be used first on account of damaging existing property needlessly and second because reducing this hill one foot in elevation would be an excessive refinement with no practical advantage. If the figures had indicated a cut of 4 or 5 feet some weight might be given to the data.

Now suppose we consider this profile from the standpoint of a *Future Truck Road* carrying 2000 trucks per day. Use Column 3, Table 12B.



This hill is a 5 per cent. hill. The capitalized value of cutting 1 ft. off from this hill per 100 trucks daily can be assumed roughly

as the difference between the capitalized operating cost on 40 feet of 5 per cent. grade and 40 feet of level grade. Using Column 3 Table 12B, this gives:

40 ft. on 5 per cent. grade	@ $74.10	=	$2964
40 ft. on level	@ 54.00	=	2160
Value per 100 trucks daily		=	$ 800 approximately.
For 2000 trucks the total value		=	$16,000 per ft. cut.

This indicates that we can cut this hill down any amount we wish.

Suppose we try a level grade "C" using a 30-ft. cut and 20-ft. fill. The rough value of this work from Stations 171 to 190 is approximately as follows.

Grade line "C"	1900 ft. on level @ $54	= $102,000
Grade line "A"	1300 ft. on 5 per cent. @ $74.10 600 ft. on average 2½ per cent. @ $55.60	= 128,000
Advantage of grade line "C" per 100 trucks daily		= 26,000
Total advantage, 20 × $26,000		= $520,000

The hill could be cut down to grade line "C" for about $60,000. Even however, for a road of this character the hill would not be cut down below grade line "D" based on a 2 per cent. grade as 2 per cent. is about the minimum required from the standpoint of cheap operation.

It can be readily seen that if roads of this kind are constructed they should be removed from the existing highways except in flat country as the deep cuts and high fills would make abutting properties inaccessible and any such grade line would raise right of way costs along existing roads way above entire new locations. It is also certain that existing roads rarely meet the requirements of engineering location that a road of this kind would demand.

If anyone seriously attempted to apply a truck operation cost analysis carried to its logical conclusion on the usual roads of today he would merely discredit his judgment (see page 60).

Case 3. Comparison of a Uniform Rate Less than the Maximum with a Combination of Rates None of Which Exceed the Maximum (Distance and Rise Fixed)

From the standpoint of expenditure of mechanical energy climbing there is no difference in grade lines "A" and "B" (figure 29 page 112).

For short grades of this nature the elements of time and wear and tear on a car are more theoretical than practical. Table 12B gives some weight to these factors.

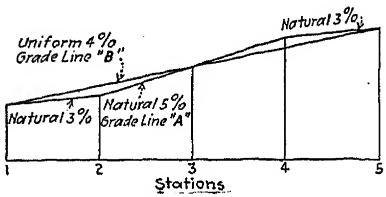


FIG. 29.

COMPARISON OF GRADE LINES "A" AND "B"

TABLE 12B.—LOCAL SERVICE ROAD COLUMN I

Grade line "*A*"	200 ft. on 5 per cent. @ $9.70 200 ft. on 3 per cent. @ $9.25	= $3790
Grade line "*B*"	400 ft. on 4 per cent @ $9.40	= $3760
Advantage of Uniform Rate per 100 vehicles		= $30
Approx. allowable expenditure per 100 vehicles		= $15

The extra cost of the uniform 4 per cent. (Grade line "B") over grade line "A" is approximately $125 so that this road would have to carry at least 800 rings per day to justify this expenditure. This volume of traffic is more than most local service roads carry.

As the rates of grade are reduced the value of smoothing out the profile becomes less so that even on main intercity routes no advantage, either theoretical or practical results from laying such a profile for rates less than 3 per cent.

The practical conclusion to be drawn seems to be that for Local Service or Secondary State Routes in thinly settled territory no expenditure is justified on such profile refinements.

On main inter-city routes on which the cities are located closer than 100 miles some expenditure on such reductions is allowable as the grades approach the maximum but they should not exceed the amounts indicated by column 2, Table 12B, as modified by the footnote. Even on such roads there is no advantage in smoothing out grades of less than 3 per cent. rate.

It is also well to bear in mind that the length of a grade and its location has a distinct bearing on its effect on traffic. That is, a short 7 per cent. grade 200 ft. to 300 ft. long located at the bottom of a long 5 per cent. grade does not in a practical way

affect the operating cost for single unit motors[1] as the speed of the cars is generally increased above normal on approaching such a hill and the momentum is effective in partially overcoming the increase in rate. Such a profile can be approximated as a uniform 5 per cent. If located at the top of such a hill the difference in rate is noticeable.

The figures given in Table 12B represent the extreme expenditure allowable and in using them to check a profile design no change should be made in the plan grade unless they show a distinct advantage in operating cost over the additional cost of grading.

SUMMARY OF MOTOR TRAFFIC CONSIDERATIONS

From a practical standpoint the following general conclusions seem sound:

1. The selection of maximum grade within the bounds of standard practice is not affected by the ability of single unit motor vehicles to climb. The long trailer train system demands low rates of ruling grade.

2. The selection of maximum grade within the bounds of standard practice is not affected by the factor of safe descent from the standpoint of single unit motors provided the alignment is safe.

3. For a fixed rise and fall and distance a combination of different rates of grade have no appreciable effect on fuel consumption. However, the total cost of motor operation including the time factor is probably slightly less for a uniform grade. This effect is not however noticeable enough to reduce the steepest grade below a reasonable maximum and has no practical effect on the use of rolling grades on intermediate profile design as the value of smoothing out minor grade irregularities becomes less as the rate of grade is reduced.

4. For a fixed rise and variable distance depending on the rate of grade, the lower the rate of grade the higher the fuel consumption and operating cost. Under these conditions the grade should be kept to the steepest reasonable rate.

5. In the matter of convenience in driving it is desirable to avoid shifting gears. The limiting rates of grade at which gears are shifted for the ordinary car on improved roads is about 6 and 10 per cent. for pleasure cars, and 5 and 8 per cent. for Standard Trucks. This however is subject to constant change and is not of much importance.

6. The value of distance saved can be closely approximated.

7. The value of rise saved can not be closely figured but it is certain that it has more money value on steep grades than on light grades.

8. In locating roads, distance can be balanced against rise but it is not possible to analyze this closely and as a rule distance should rarely be increased particularly if good alignment is lost unless it is necessary to get a

[1] By single unit motors are meant trucks without trailers.

reasonable maximum grade or unless a noticeable localized rise and fall can be eliminated by a short additional distance. (Use Table No. 12B page 104 for comparisons of this nature.)

9. Ruling grades need not be consistent in rate as far as ordinary motor traffic is concerned as they do not limit the load of single unit hauling rigs. Ruling grades should be consistent if the trailer train system controls the design.

It can be seen that the requirements of ordinary motor traffic have less definite claims for consideration in reducing the *rate of maximum grades* than Horse Traffic but have more claim than horse traffic in the matter of reducing distance and rise and fall on account of the large amounts of money annually spent on operation costs. Summarizing we can say that ordinary motor traffic warrants higher rates of maximum grades than horse traffic but demands short distance and less rise and fall on steep grades. The reduction of rise and fall on light grades is of very little practical value. For certain special conditions where the trailer train must be considered, maximum grades may well be reduced below even the limits required for horse traffic.

Effect of Maintenance Cost on the Selection of Maximum Grades.—The maintenance of shoulders, ditches, and water-bound macadam, gravel or natural soil surfaces increases in cost rapidly on grades over 5 per cent. From the standpoint of Maintenance cost 5 per cent. is the logical maximum rate.

Effect of Safe Footing on Maximum Grade.—In regard to the matter of safe team footing, it is possible to select some type of pavement which will satisfy this condition for any grade used but a change in surfacing to meet this requirement is often omitted on account of expense and more often omitted by careless design. Most of the rigid pavement types give satisfactory footing up to 5 per cent. which is the practical limit without special design. Bituminous macadams can, by variations in manipulation, be made suitable for grades up to 8 per cent. Plain macadams give good footing for any grade but are expensive to maintain over 5 per cent. From the standpoint of team footing 5 per cent. has a distinct advantage on main roads where rigid types are desirable, and 7 or 8 per cent. is a reasonable limit on side roads where some form of macadam or gravel will probably be used. Team footing is however, becoming less important as a deciding factor.

Effect of Farm Hauling on Maximum Grade.—From the standpoint of accommodating ordinary farm team loads 7 per cent. is

the logical ruling rate. This is based on a load of 5000 pounds for farm hauling which includes wagon weight. The records of produce dealers in the Eastern States show that the ordinary wagon weighs about 1350 lb. and that 3500 lb. is a large net load. This load of 2.4 tons corresponds with the maximum theoretical load for 7 per cent. hard surfaced grade. Team loads of six tons would be very unusual which means that the ideal teaming grade of 2½ per cent. need not be considered except in level country where it can be obtained without much extra cost.

Effect of Construction Cost on Maximum Grade.—From the standpoint of construction cost 5 to 7 per cent. can generally be built without excessive expenditure even in hilly country.

Maximum Grades in Present Use.—The maximum grades in present use represent the best judgment of engineers from all over the world backed by practical experience and traffic tests of generations. It is true that they are largely based on factors of horse traffic, reasonable construction and maintenance costs but the author believes that these factors are still the most important deciding elements in the selection of maximum grade for most roads. The following Table 13 gives the rates in common use and is probably the most reliable basis for design that can be used.

TABLE 13.—MAXIMUM GRADES IN FOREIGN COUNTRIES

Location	Mountainous districts, per cent.	Hilly districts, per cent.	Level districts, per cent.
Prussia	5	4	2½
Hanover	4	3⅓	2½
Baden	8	6	5
Brunswick	5½	4	3
Holyrod Road in England	6	3½	

Military highway over the Alps—Italian side, 4½ per cent., Swiss side, 6 per cent.

Location	National roads, per cent.	Departmental roads, per cent.	Subordinate roads, per cent.
France	3	4	6

MAXIMUM GRADES IN THE UNITED STATES

State	Main roads, per cent.	Side roads, per cent.	Unusual cases, per cent.
New York	5	7 and 8	11
Massachusetts	5	7	
Connecticut	5		
New Jersey	5	6 and 7	9
Michigan	6		
Missouri	5 and 6		
Washington	5	5	
Illinois	6	....	9

United States National Forest Roads (Mountainous Districts)

1st class roads........ Long grades 5 per cent.—short grades 7 per cent.
2d class roads........ Long grades 7 per cent.—short grades 10 per cent.
3d class roads........ Long grades 10 per cent.—short grades 12 per cent.
State of Colorado (main mountain roads).................... 6 per cent.

mended Practice Maximum Grade Design.—From the oints of horse traffic, single unit motor traffic or trucks ne trailer, safe footing and economy of construction and maintenance the following recommended rates of maximum grades will give moderately good satisfaction. In unusual cases the possibility of the extensive use of long trailer trains would tend to reduce these recommended rates but the author wishes to emphasize the opinion that very few roads need be designed at this time primarily for long trailer trains. The following rates are satisfactory for the ordinary motor equipment used by the great majority of road users and additional expenditure would not be warranted for the benefit of a few men. *For the effect of dangerous alignment on maximum grade see page* 140.

Main Commercial Roads in Flat Country.—Long 2 per cent. ruling grades are desirable but do not justify much additional construction cost. Any long ruling grade up to 5 per cent. will probably be satisfactory. Short 6 per cent. are not inconsistent. A large volume of hauling by trailer trains might warrant reductions below usual practice provided the interests operating such haulage paid the increased cost of construction.

Main Commercial Roads in Hilly Country (*Well Settled Districts*).—Long 5 per cent. ruling grades are desirable and justify considerable expenditure provided they do not increase the total distance. Seven per cent. grades are probably justified to prevent increase in distance for a fixed rise. Long 6 per cent. grades are fairly satisfactory but as a rule if 5 per cent. cannot be reasonably obtained it is just as well to jump to 7 per cent. Short 7

or 8 per cent. grades are not inconsistent in connection with long 5 per cent. and 6 per cent. grades provided the element of safe team footing is considered.

Main Roads Pioneer Districts.—Long 5 per cent. grades are very desirable provided they do not increase the total distance particularly if the road is a natural soil road and considerable horse traffic prevails. Any long grade up to 7 per cent. is fairly satisfactory. Short 7 and 10 per cent. grades are not inconsistent except for trailer trains. Grades higher than 7 per cent. are not, however, in much favor on account of danger and high maintenance cost.

Side Agricultural Roads or Unimportant Pioneer Roads.—Any long grade up to 7 per cent. is satisfactory. Short 10 per cent. grades are consistent in connection with a 7 per cent. ruling provided the element of safe footing is considered. Grades steeper than 7 per cent., however, have a high maintenance cost.

Scenic Roads.—Long 6 per cent. grades are convenient on account of preventing gear shifts. Ten per cent. is not unreasonable for such roads except that on a 10 per cent. grade the alignment should be easy as later discussed and the maintenance cost is high.

Effect of Alignment.—Sharp curves affect steep grades as taken up under the subject of Alignment (see page 138).

Unusually High Rates of Grade.—Grades as high as 11 per cent. have been constructed on State improved roads in New York and as high as 9 per cent. in New Jersey and Illinois but the general opinion of the departments under which these grades were built is that they would not again use such a high rate except in villages where any material change in street elevation would damage valuable properties. Outside of corporations it is bad practice to use long grades of greater rate than 7 per cent. for if any road is of sufficient importance to warrant engineering plans for the future it is certainly of sufficient importance to warrant a reduction in grade to a reasonable rate.

Consistent Maximum Grades.—The design should be consistent if horse traffic is considered. Take for example a road between two shipping points. It is first necessary to determine the portion tributary to each terminal and then the practical grades on all the hills on each portion in order to decide what consistent ruling grade can be adopted without excessive cost. There is no object in reducing a hill from 7 to 5 per cent. provided the total rise remains fixed with a large expenditure if nearer the terminal there is a grade that cannot be reduced below 7 per cent. It should be borne in mind, however, that the nearer you approach the shipping or market point, the more traffic the road will have, and if the hills are naturally

flatter the ruling grade should be reduced. The direction of heavy traffic on each hill should be determined and considered. Ordinary motor traffic does not require consistent maximum grades but the trailer train method does require them. Considerable expenditure is justified to obtain consistent grades for the benefit of team hauling on local service roads.

Effect of Maximum Grade on Cost.—Money spent on the reduction of maximum grade is never wasted unless distance is increased for a fixed rise by a grade lower than a reasonable maximum. It is not good policy to spend large sums to reduce below 5 per cent. in hilly country or 2 per cent. in level country even where distance is not increased. The effect on cost of the selection of a 5 per cent. in place of a 6 per cent. or a 6 per cent. in place of a 7 per cent. depends largely on the method of con-

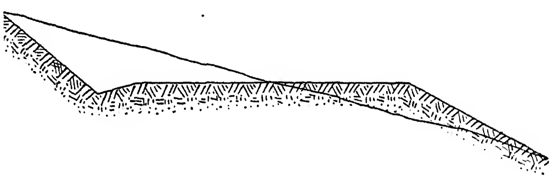


Fig. 30.

struction that must be used. Where locations are fixed by well established right-of-ways and permanent structures and the cost of new right-of-way is very high grades are generally reduced by cut and fill. Under these conditions the effect of the selection of rate is very marked and no general relation can be established as each case is a law unto itself. To show the fluctuating amounts of excavation per mile for different improvements based on different rates of ruling grade where cut and fill was used, Table 14, page 120, has been compiled.

Unfortunately many of the roads in the older states were not laid out on natural engineering locations and grade improvements are expensive either on account of excessive cut and fill or the high cost of new right-of-way on a better location. In mountain road or ordinary locations in newly settled districts the question of right-of-way rarely handicaps the design and easy grades are obtained at moderate cost by natural locations which avoid steep adverse grades by going around a hill or develop moderate grades on a long climb by a longer distance. In

climbing on a sidehill location the road section is generally what is known as a balanced section, that is, the cut just makes the fill by side displacement. The amount of excavation per mile is not affected by the rate of grade but sometimes the length of road is affected.

Generalizing we can say that the effect of grade reduction on cost is not as marked as for cut and fill methods and that roughly the relation of cost to grade depends on the length which is

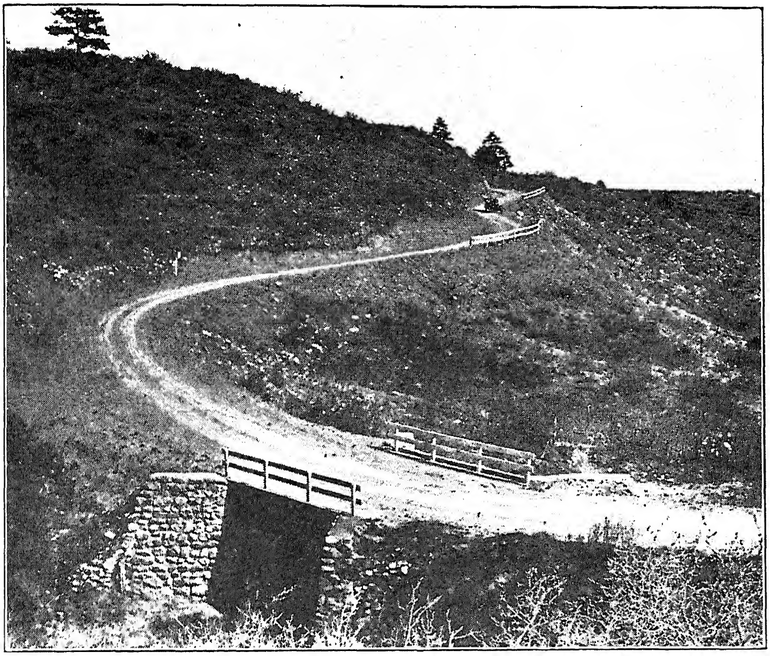


FIG. 31.—Balanced side hill section.

often inversely proportional to the rate; that is, where cut and fill is used a 5 per cent. grade might easily cost three or four times as much as a 6 per cent. grade but where sidehill location is possible a 5 per cent. would rarely cost more than $\frac{6}{5}$ as much as a 6 per cent. This is of course affected by all sorts of local conditions and may not apply at all but is true by and large and serves to illustrate the relation of rate to cost. To illustrate (fig. 32): If the difference in elevation between A and B is 1000 feet a 6 per cent. grade would require approximately $3\frac{1}{3}$ miles of length and a

5 per cent. grade 4 miles to make the ascent. If the direct distance between *A* and *B* is less than 3⅓ miles the lengths of the two lines will be approximately as given. If the distance from *A* to *B* is more than 4 miles there would be little difference in the length as it would merely mean that the 5 per cent. started to climb

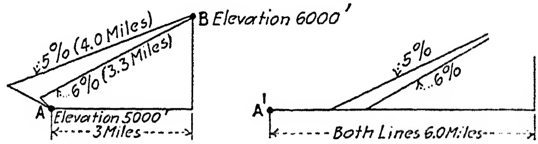


FIG. 32.

sooner than the 6 per cent. Under most conditions the cost would be more affected by the character of the excavation on the different locations and by the number of switchbacks required for the smaller rate. *The difference in cost due to the difference in rate of maximum grade in mountain location does not often warrant the adoption of excessive grades.*

TABLE 14.—COMPILED FROM THE 1908 AND 1909 REPORTS OF THE NEW JERSEY HIGHWAY COMMISSION

Name of road	Length in miles	Maximum original grade, per cent.	Maximum improved grade, per cent.	Excavation in cu. yd. per mile
May's Landing	14.0	7.0	3.2	2,220
Rivervale	5.0	8.5	5.0	4,680
Westwood	1.2	5.2	4.5	2,500
Franklin Turnpike	1.6	8.0	2.8	8,200
Summit	1.9	13.0	6.5	5,200
Lamberton	3.9	2.8	2.8	540
Westfield	3.1	4.5	2.9	6,500
Blue Anchor	2.3	2.5	2.0	3,200
Malaga	5.7	4.2	2.0	1,700
Whitehouse	6.5	12.5	5.0	4,100
English Creek	6.7	6.0	3.9	2,000
Paterson Plank Road	2.3	Level	Level	(Emb.) 50,000
Yesler Way	2.7	12.0	6.5	5,700
Camden	2.4	6.7	4.0	5,200
Evesham	2.4	6.4	3.7	3,500
Schellenger's Landing	2.1	3.4	1.1	5,000
Goshen	2.6	3.4	1.4	4,500
Tuckahoe	4.3	4.1	1.6	8,100
Hopewell	2.0	7.6	5.0	3,800

Table 14.—Compiled from the Records of the New York State Highway Commission

Plans for 1911

Name of road	Character of country	Maximum improved grade, per cent.	Width of section between ditches, ft.	Exc. in cu. yd. per mi.
Pittsford—North Henrietta.....	Rolling	5.0	24	2500
Indian Falls—Corfu...........	Flat	2.6	24	2800
Pembroke—East Pembroke.....	Hilly	5.0	32	3600
Livonia—Ontario County Line..	Hilly	8.0	32	5500
Livonia—Lakeville.............	Hilly	8.0	32	4500
Avon—Lima..................	Hilly	8.0	32	3300
Sea Breeze—Nine Mile Point...	Hilly	8.0	26	6600
Bliss—Smith's Corners.........	Rolling	5.5	26	3400
Wales Center—Wales..........	Hilly	8.0	28	5700
Scottsville—Mumford..........	Rolling	5.0	32	3400
Ridge—Rochester—Sea Breeze..	50 % Flat 50 % Hilly	1.5 5.0	32 44	3350
Medina—Alabama.............	Rolling	5.0	28–32	2800
Pavilion—Batavia.............	Hilly	10.0	22–30	2950
Parma Corners—Spencerport—North Chili..................	Flat	6.0	32	2320

TABLE 14 (*Continued*).—COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION

Plans for 1908 and 1909 (Selected Roads)

Name of road	Character of country	Max. improved grade, per cent.	Width of section between ditches, ft.	Exc. in cu. yd. per mi.
Hamburg—Springville Sect. I...	Rolling	6.0	30	1920
Hamburg—Springville Sect. II..	Hilly	7.0	30	3100
Collins—Mortons Corners......	Hilly	7.0	32	2250
Clarence Center...............	Flat	2.5	28	2200
Orchard Park—Griffin's Mills...	Hilly	8.0	28	2000
County Line..................	Flat	5.0	28–32	2100
Geneseo—Avon...............	Hilly	5.3	32	2200
Geneseo—Mt. Morris..........	Hilly	6.0	32	3460
Alden—Town Line............	Flat	6.0	22–28	1960
Pittsford—Mendon............	Hilly	6.0	32	3000
Pittsford—Despatch...........	Hilly	5.0	24	3600
Clover Street Section I.........	Hilly	8.0	28	2550
Clover Street Section II........	Rolling	4.5	32	3000
Rich's Dugway................	Hilly	7.2	20–28	5000
Left Fork—German Church....	Rolling	6.2	28	2000
Goodrich Road..............	60% Flat 40% Rolling	5.0 6.0	26–32	3100
Hamburg—North Collins.......	Hilly	9.0	22–32	4200
Lawton—Gowanda......	Hilly	7.5	32	5300
Chili..............	Rolling	5.0	28	2800
Brooks Avenue......	Flat	4.6	24–30	2240
Lyell Avenue..	Flat	2.2	26–30	2400
Barnard's Crossing......	Flat	4.4	22	2174

TABLE 14 (*Continued*).—COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION

Plans for 1910

Name of road	Character of country	Maximum improved grade, per cent.	Width of section between ditches, ft.	Exc. in cu. yd. per mi.
Lake Part 2 & Sweden 4th Sect.	Flat	3.8	32	2560
Warsaw—Pavilion	Flat	5.0	28–32	3900
East Henrietta—Rochester	Rolling	3.8	32	2300
Olean—Hinsdale	Flat	2.6	28–32	4000
Leroy—Caledonia (1.5 miles)	Rolling	5.0	32–40	1950
Shawnee—Cambria	60 % Flat 40 % Hilly	2.2 7.0	28–32	3150
Roberts Road	Rolling	3.1	32	3230
Sanborn—Pekin	Flat	2.4 One hill 5.0	32	2800
Oak Orchard, Part 2	Rolling	4.4	30–32	2300
Levant—Poland Center	Hilly	5.0	28–32	4000
Dansville—Mt. Morris, II	Hilly	4.1	24	6200
Castile Center—Perry Center	Flat	3.6	30	2820
Lake Shore—Lackawanna City	Flat	0.7	28–32	2120
Eighteen Mile Creek	Hilly	7.0	28–32	6100
Albion Street—Holley	Rolling	3.7	32	3440
Pembroke—East Pembroke	Rolling	5.0	32	3800

TABLE 14 (*Continued*).—COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION

Plans from 1898 to 1907. (Selected Roads.)

Name of road	Character of country	Maximum improved grade, per cent.	Width of section between ditches, ft.	Exc. in cu. yd. per mi.
East Avenue	Rolling	5.0	22	8160
Pittsford	Rolling	5.0	22	5840
Fairport	Rolling	5.5	20–22	6580
Ridge Road	Rolling	3.3	26	2150
Buffalo Road	Flat	2.0	22–25	1700
White's Corners Plank Road	Flat	3.5	22	4600
Orchard Park	Flat	3.9	20	4200
Transit, Sections I & II	Flat	4.6	22	2100
Hudson Avenue Road	Rolling	3.1	22	7100
West Henrietta	Flat	5.5	22	3400
Scottsville, Section I	Flat	4.0	22	2000
Scottsville, Section II	Rolling	5.0	22	2100
Monroe Avenue	Flat	4.5	22–24	1850

An examination of the 1909 report of the New York State Highway Commission shows that the largest excavation per mile on roads built by the State from 1898 to 1908 was as follows:

Delaware Turnpike Road........1.04 miles...16,800 cu. yd. per mile
Delaware Turnpike Road........6.5 miles... 6,800 cu. yd. per mile
North Creek-County Line........4.12 miles...10,300 cu. yd. per mile
Highland Lake-Tompkins Cove...5.88 miles...10,100 cu. yd. per mile

and the least excavation as follows:

Main Street, Section II...................... 986 cu. yd. per mile
Babylon-Bay Shore......................... 735 cu. yd. per mile

TABLE 14.—COMPILED FROM THE REPORTS OF THE MASSACHUSETTS STATE HIGHWAY COMMISSION. 1896

Name of road	Length in miles	Maximum improved grade, per cent.	Width of section between ditches, ft.	Exc. in cu. yd. per mi.
Andover	0.6	4.9	24	6000
Brewster	1.0	3.36	21	2607
Dalton	1.5	6.0	30	1920
Gloucester	1.6	5.0	21	3200
Granby	0.63	2.7	21	5300
Great Barrington	1.0	2.6	21–24	2300
Hadley	1.49	4.0	21	8930
Munson	0.93	2.95	21	3000
Norfolk	1.2	5.3	21	3350
North Hampton	0.56	1.25	26	4300
Pittsfield	1.0	4.25	21	4700
Tisbury	1.93	4.40	21	7540
Westport	3.0	1.7	24	1500
Wrentham	1.62	4.0	21	3700
Walpole	1.61	6.0	21	5600
Duxbury	1.05	3.8	21	3800
Fairhaven	1.45	4.0	21	1200
Fitchburg	0.97	6.0	21	4500
Goshen	1.91	5.0	21	9700
Marion	1.48	5.0	21	1500
Mattapoisett	1.16	4.25	21	1810
Lee	1.5	5.16	..	3500
Leicester	2.0	5.0	..	3800

No criticism of wasteful expenditure on maximum grade can be made in regard to most of the plans as now designed but in many instances the profile feature of intermediate grades is not carefully analyzed.

Intermediate Grades.—Intermediate grades include all rates between the maximum and minimum grades for the particular job in question. They afford the greatest chance for reasonable economy of earthwork of any part of the grading design and usually receive the least attention. From the standpoint of traffic they have practically no value on Local Service Roads and only a slight value on Commercial Roads; their proper use, however, controls the convenience and suitability of the road to abutting property and controlling conditions. In laying a profile grade the controlling points must first be considered; these are

highwater levels of flood areas, elevations of existing bridges, railroad crossings, all points where deep cuts or high fills would damage the approaches to valuable property connections with other highways, portions of the road previously improved and in villages the elevation that will permit future widening and curbing that will fit the case.

Current practice handles most of these controlling features well with the exception of grades through villages which are almost without exception too high for future widening and curb finish. Designers are cautioned to use city street methods and to make the elevation the same as if a full width curbed pavement was being designed.

Effect of Intermediate Grades on Cost.—All of these controlling points must be satisfied but they usually affect only a small

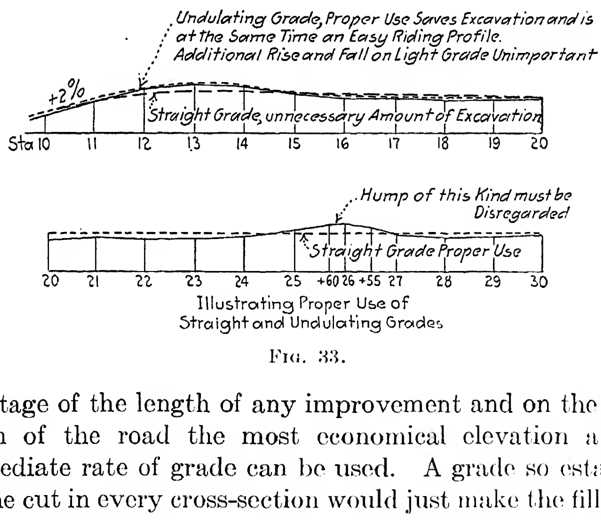


FIG. 33.

percentage of the length of any improvement and on the greater portion of the road the most economical elevation and any intermediate rate of grade can be used. A grade so established that the cut in every cross-section would just make the fill at that point would result in the least possible excavation and the cheapest kind of grading methods. This condition can never be realized but the nearer it is approximated the nearer we get to the most economical grading design. Where intermediate grades are applicable there is no restriction on any combination of rates as they have no effect on traffic loads and very little effect on motor operation cost and by an intelligent selection the ideal solution can be closely approximated. The cheapest and most satisfactory profile can be obtained by the use of the "rolling grade;" by this is meant a profile made up of a combination of

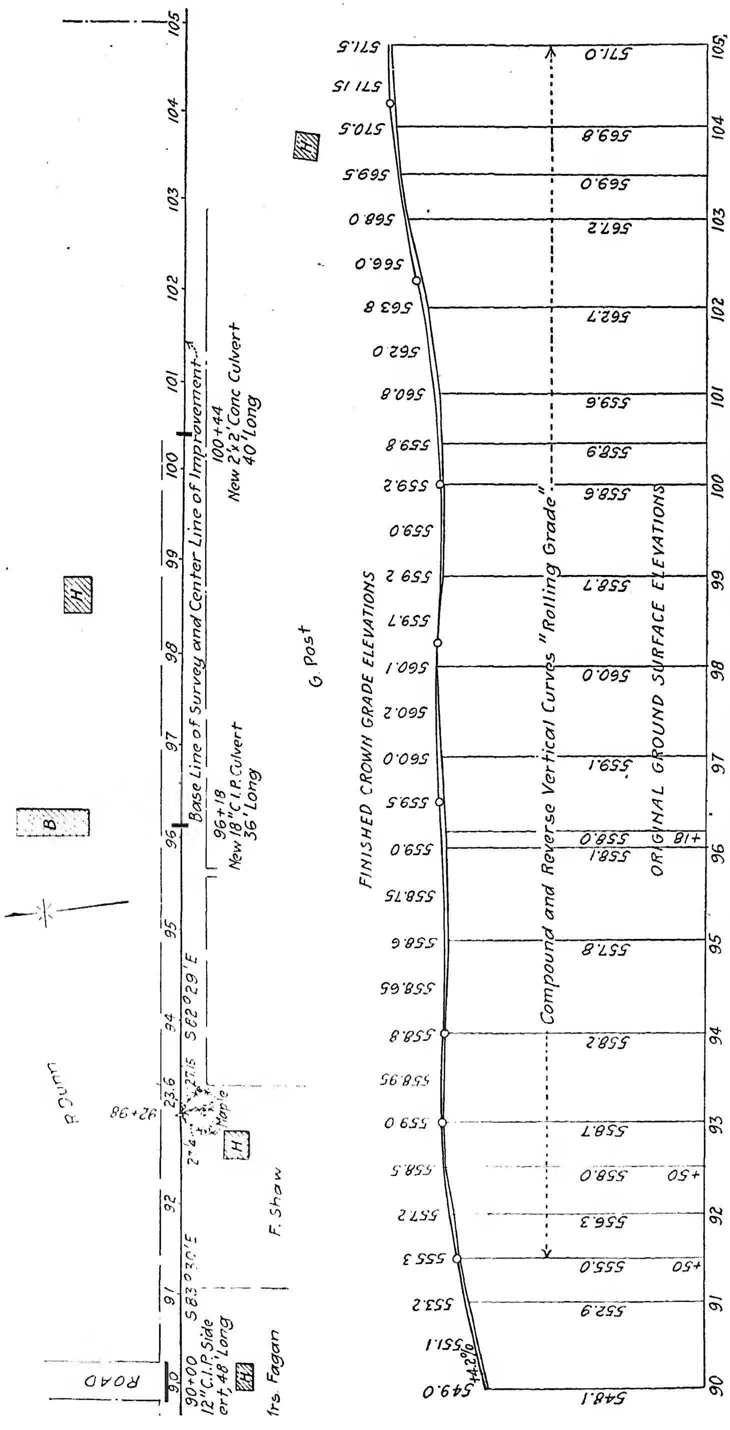


FIG. 34.—Example of "rolling grade" used on state road construction.

simple, compound or reverse vertical curves, connected by tangent grades only when the tangent grade is the most economical or is necessary to prevent a series of short humps and hollows. Long straight grades are not required, a mistake easily made by engineers trained in railroad work. Short grades are not objectionable and reverse vertical curves ride easily if well built. The rolling grade is also more pleasing in appearance than a straight profile if not carried to extremes. The detail methods of laying such a grade are described in the third book of this series. It appears that there is too much tendency to cut the top of each knoll and fill each hollow for very little practical advantage results from reducing a natural 4 per cent. grade to a 3.5 per cent. or a 3.5 per cent. natural grade to a 3 per cent. if the ruling grade is 5 per cent. and the rise remains fixed.

We can not overestimate the importance of avoiding this tendency as the plans of about 2000 miles of road constructed in the last ten years which the writer has looked over in this connection show a needless expenditure of at least a million dollars for grading which had no practical value whatever. This element of costly design in current practice is probably due to the fact that the savings are not spectacular at any one place but if the principle is consistently used the total result is spectacular.

It is also undoubtedly true that the previous railroad training of many road engineers has had a detrimental effect on intermediate profile design. From the standpoint of highway design railroad practice overemphasizes the elimination of minor rise and fall on light grades. The author has personally applied the "rolling grade" principle on construction work for the last ten years and found that the saving averaged about $500 per mile (using the 1920 scale of prices these savings would have averaged $1000 per mile). A systematic grade line design will also often change the method of grading as well as reduce the yardage. To illustrate we will cite the Heber Fruitland Road in Utah. The original design used long straight railroad grades which required wagon haul; the redesign used a rolling grade which not only reduced the amount of excavation by about 30 per cent. but also practically eliminated wagon haul for most of the work and made it possible to handle the dirt with slip scrapers and road machine blade scrapers. This reduced the cost per cubic yard about 25 per cent. The quantity reductions plus the unit cost reductions amounted to approximately 50 per cent.

In order to strengthen the force of the argument for "rolling grades" the following statement by Mr. G. R. Harr, Office Engineer of the Indiana Highway Commission is inserted. The work to which he refers was done under the direction of Mr. H. K. Bishop, Chief Engineer.

"When we started here last May a year ago we had some plans previously prepared that had long straight tangent railroad grades. We revised these plans using rolling grades having long and short vertical curves. In so doing we reduced the excavation very materially.

"From what I remember of the projects and the work on the same we saved from about 500 yd. to the mile up to 4000 yd. to the mile. On one project the total excavation was cut practically in half."

The Effect of Arbitrary Profile Limitations on Cost.—A common grade line limitation calls for tangent grades drawn to intersection with simple vertical curves easing off the apex and insists on 100 ft. of tangent grade between the ends of these vertical curves. This sounds scientific but has no practical value and is cited to illustrate the danger of ill considered limitations. A specification of this kind often increases the grading by from 500 to 1000 cu. yd. per mile an example of which is given below.

Pittsford-N. Henrietta Road in New York State

Length 2.67 miles

Original Design	Revised Design
Maximum grade 5 per cent.	Maximum grade 5 per cent.
Profile.—Straight grades with 100 ft. of tangent between vertical curves.	Profile.—Rolling grade.
Original amount excavation 11,450 cu. yd.	Revised amount 9300 cu. yd.

(A saving of 800 yd. per mile)

In conclusion we may say that the matter of intermediate grades needs more care than it often receives.

MINIMUM GRADES

Hard Surfaced Pavements.—Many road books claim that level grades should not be used because of the liability of water standing in ruts and that a certain minimum grade should be adopted that will insure their longitudinal drainage. Baker states in his "Roads and Pavements" that for macadam roads English engineers use a minimum grade of 1.5 per cent., French

engineers 0.8 per cent. and that American practice favors 0.5 per cent. Let us see what this means.

For a 1.5 per cent. grade the fall would be $\frac{1}{5}$ in. per ft.
For a 0.8 per cent. grade the fall would be $\frac{1}{10}$ in. per ft.
For a 0.5 per cent. grade the fall would be $\frac{1}{16}$ in. per ft.

The flattest crown that is ordinarily used even on bituminous macadam is $\frac{3}{8}$ in. per ft. or twice as much as the greatest longitudinal fall in the above list. For long ruts the longitudinal grade is of course effective but the patrol system of maintenance is supposed to prevent their formation and for short small depressions the crown slope must furnish the drainage. There seems to be no reason why level grades should not be used on hard surfaced roads; on such stretches the crown can be increased slightly to insure transverse drainage and the ditches given a minimum longitudinal fall of 0.2 to 0.5 ft. per 100 ft. depending on the soil to insure the longitudinal drainage of the surface water.

Earth Roads.—On earth or gravel roads attention should be given to minimum grades as for these types they have some value but not enough to warrant much expenditure.

It is advisable to use a 0.4 per cent. to 0.5 per cent. grade where much snow or rain occurs but in the arid regions no minimum restriction should be specified.

Adverse Grades.—Adverse grades are defined as grades contary to the general rise and fall of the road between terminals or controlling points. It is important to avoid them on mountain road locations where the prime object is to gain elevation or on main Commercial Roads where the factor of rise and fall has considerable value. They are not a serious drawback for the usual road and can not be avoided in ordinary rolling topography. This is so self-evident that it hardly seems necessary to state it. There is no serious objection to short adverse grades even on a long climb if by their use the alignment can be bettered and excavation saved in crossing a small gully. There is no objection to adverse grades of 2 per cent. or less on any road. The main objection is to long adverse grades introducing considerable additional rise and fall which could be avoided by a better engineering location. This point is generally considered in the selection of the general route and is covered by the comparison of routes in the preliminary investigation.

Vertical Curves.—Vertical curves between tangent rates of grade add to the safety, convenience and appearance of the highway. Vertical curves as a rule are picked out to fit the natural profile and in easy rolling topography this method of selection need not as a rule be modified for any other consideration. However, there are cases where the length of the vertical curve at the summit of a hill controls the length of sight ahead and under these conditions certain minimum lengths are stipulated. A reasonable basis for decision in these cases appears to be founded on a clear sight ahead at all times of 350 ft. for Main Commercial Special Service roads and 250 ft. for Local Service roads except in mountainous regions where the sight distance requirement can not be reasonably obtained. On this basis the following table is compiled assuming that the line of sight is 5.5 ft. above the ground at the two ends and tangent to the vertical curve.

TABLE 15.—BASED ON A LINE OF SIGHT 5 FT. 6 IN. ABOVE THE GROUND AT BOTH ENDS

Algebraic difference in rates of grade per cent.	Minimum length of vertical curve in feet for a sight distance of 250 feet	Minimum length of vertical curve in feet for a sight distance of 350 feet, feet
6	...	...
8	...	150
10	50	250
12	135	330
14	190	400
16	225	450

As a matter of fact merely on account of appearance and convenience in motor operation to prevent disagreeable checking in speed at the foot of hills the author never uses a vertical curve less than 100 ft. long between grades having an algebraic difference in rate of 5 per cent. or less. Vertical curves are generally used between all grades having an algebraic difference of over ½ of one per cent.

Minimum length of vertical curves from the standpoints of convenience, appearance and sight distance can be assumed roughly as follows. There is no limitation on maximum length except that the curve should fit the profile without excessive

grading. Vertical curves should be made as easy as possible without running up the cost needlessly.

TABLE 16.—RECOMMENDED MINIMUM LENGTHS OF VERTICAL CURVES BETWEEN TANGENT GRADES

Algebraic difference in rates of tangent grades, per cent.	Minimum length of vertical curves on local service roads, feet	Minimum length of vertical curves on special service commercial roads, feet
5 or less	100	100– 150
8	150	200
10	200	300
12	250	400
14	270	450
16	300	...

Summary of Grades.—The discussion of economic grading design may be summarized as follows:

The road value of reasonable maximum grades and small amounts of rise and fall on steep grades can not be overestimated. Any expenditure on these features is justified so long as it is consistent with the theory of cheap operation. The use of properly proportioned short maximum grades in connection with long ruling grades is a source of justifiable economy and works no hardship except for long trailer trains. The use of the highest reasonable maximum to shorten distance for a fixed rise results in considerable construction saving in many cases and is justified on the score of reducing motor operation costs. *Distance should never be increased for a fixed rise to reduce grades below a reasonable maximum.*

Minimum center line grades have no road value on hard surfaced roads and only a slight value on earth roads. Minimum ditch grades are important.

The traffic value of intermediate grades is negligible on local service roads and only of minor importance on Special Service roads. Intermediate grade line design has a large effect on grading cost and is entitled to very careful consideration. The most common faults of the ordinary treatment of these grades are the needless reduction of light natural grades and the use of long straight railroad rates of grade. *There is no practical advantage whatever from the use of long uniform light rates of grade*

where the total rise and fall is not changed and very little real value is accomplished by the reduction of minor rise and fall occurring on light natural grades.

ALIGNMENT

Alignment affects the safety, speed, ease and hauling power of traffic and the cost of Road Construction. Highway location is controlled at many places by the effect of curvature on maximum grade and the effect of alignment on construction cost. Sharp alignment modifies the allowable rate of grade, the width of pavement, width and shape of section and increases the need for substantial safety devices such as retaining wall or concrete or steel cable guard rail. At this point in the discussion it is only necessary to consider the factors in connection with alignment which would naturally control the field survey location namely; the effect of alignment on grade, cost of construction and safe sight distance for traffic. The effect of alignment on banking and widening pavements on curves and on the design of guard rail, etc. will be taken up in Chapter V and Volume II.

In well settled communities alignment is practically controlled by the existing road right of ways except where short relocations will materially reduce distance, needless rise, extreme grade or danger to traffic. In sparsely settled communities alignment is not handicapped by right of way difficulties. *As a general proposition dangerous or crooked alignment should not be introduced to reduce grades below the maximum.* If it is necessary in order to get the maximum grade or to keep the construction cost within reason well and good. By this is meant that a straight road on a 5 or 7 per cent. grade is generally more satisfactory than the same road on a 3 or 5 per cent. grade with a dangerous turn. If the lower grade can be obtained without dangerous alignment and without increasing distance, all well and good. However, a reasonable maximum grade should not be sacrificed on a side hill location for better alignment as future improvements, grading, etc. can reduce alignment danger much more easily than it can reduce grade by an entire relocation and the danger at a few sharp bends on a long climb having normally safe alignment can be reduced by flattening the grade at the danger point. That is the necessity of one or two sharp switchback turns to get a long reasonable maximum rate would not warrant an increase in grade above the reasonable maximum

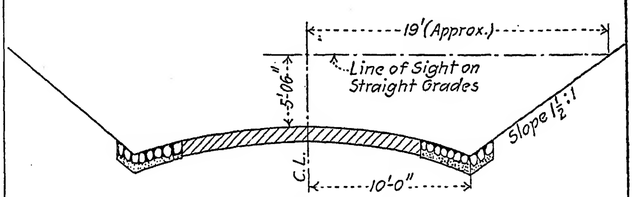
in order to eliminate these turns. Short maximums in connection with long lower maximums are warranted to improve alignment.

Dangerous Alignment.—Sharp curves are not particularly dangerous for slow horse traffic but they are extremely dangerous for high speed motor traffic particularly on through roads used by drivers not familiar with the locality. It is of course impossible to protect traffic from the carelessness of speed maniacs but the danger of collisions can be materially reduced by alignment which permits the driver to see ahead a reasonable distance at all times. Cars driven at high speed are liable to leave the road on almost any curve as the author's observation has been that about as many cars go off moderately easy curves up to 500 radius as they do on very sharp curves on account of the tendency to take the easier curves at excessively high speed. However, the danger of collision is less as it gives the other man a chance to protect bimself. We are not particularly grieved if a fool does commit suicide. A touring speed of 20 to 30 miles per hour is reasonable for main road travel in ordinary rolling topography. Tests on the braking power of automobiles show that a passenger car travelling 20 miles per hour can be stopped in 40 ft., and one going 40 miles per hour in 140 ft. by the use the emergency brake. As a matter of fact, brakes are not always efficient, a driver requires a little time to realize that danger exists after first seeing the approaching car so that the determination of safe sight distance is largely a matter of judgment.

Sight Distance.—The author has written to a large number of Automobile Clubs over the country and in the main they agree on 250 to 300 ft. as the minimum safe sight distance ahead at all times. The shorter distance is used on local service roads where most of the drivers are familiar with the road and the longer distance for main routes carrying foreign traffic not familiar with the existing alignment. This corresponds with the practice of various highway departments. Roads built with this limitation seem satisfactory to traffic. A sight distance of this kind does not necessarily depend on alignment unless the curve is in cut. Alignment is not affected by sight distance unless the curve is in cut or along a side hill where the cut slope is on the inside of the curve or where buildings or trees occur along the right of way line. The smallest radius of curvature that is permissible to give a certain sight distance depends on

the width of the road section in cut and can be easily worked out diagrammatically for any special case. To give an idea of the various minimum alignment radii required for the different sight distances for curves in cut the following table is inserted.

150' Sight Distance A	150' Sight Distance B	200' Sight Distance A	200' Sight Distance B	250' Sight Distance A	250' Sight Distance B	300' Sight Distance A	300' Sight Distance B	350' Sight Distance A	350' Sight Distance B	400' Sight Distance A	400' Sight Distance B
			Values given below are the radii in feet								
158	286	272	505	420	786	600	1130	815	1536	1062	2005



Contracted Section in Deep Cuts.
This is the Section on which this Table is Based

TABLE 17.

This table is compiled for the minimum width section used in New York State in 1919. Similar tables can be prepared for the standard sections in use in any particular locality. Column A in each case applies where the curve is on a straight grade and the line of sight is 5 ft. 6 in. above the crown grade of the road. Column B in each case applies to where the curve is at a change of grade and the line of sight is just above the ground at the ditch line.

The radius for a specified sight distance can be figured by the formulæ $R = \frac{M}{2} + \frac{C^2}{8M}$ where

R = The road ℄ radius in feet.

M = The distance in feet off the ℄ of the road where the line of sight comes tangent to the cut slope or any other obstruction.

C = Required length of sight distance in feet.

The sight distance for any specified alignment radius and standard section can be increased by "Daylighting" the curve as shown in Fig. 35 (page 136).

This method has the distinct advantage of cheapening the grading cost and it also gives the driver a chance to see ahead even if he hugs the inside of the curve.

hows a proposed improvement of this nature on
) New York State.

actice **Minimum Curvature.**—Sharp curves on
r at the foot of such grades are not safe. Good

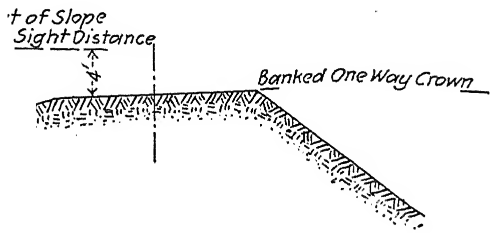


FIG. 35.—"Daylighting" a curve.

practice calls for a minimum radius of 300 to 400 ft. for these cases in ordinary topography. Right angle turns even on level stretches are an abomination of the Lord. A minimum radius of 200 ft. for such cases increases the convenience of the road and is greatly appreciated by the road users.

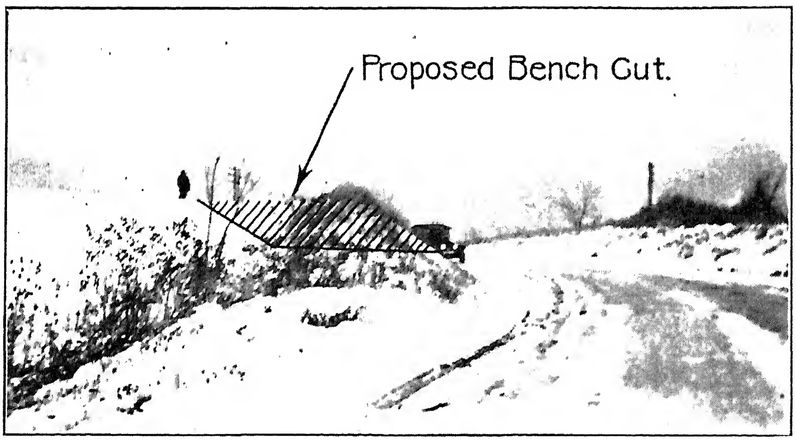


FIG. 36.—"Daylighting a curve" main intercity state route no. 30 (New York State).
Radius of curvature road center line 287 ft.
Present sight distance 240 ft.
Proposed sight distance 340 ft.

France and Austria have used minimum radii of 100 to 165 ft. on main roads and as low as 50 ft. radii on District roads but these limits are hardly suitable for fast traffic. The use of

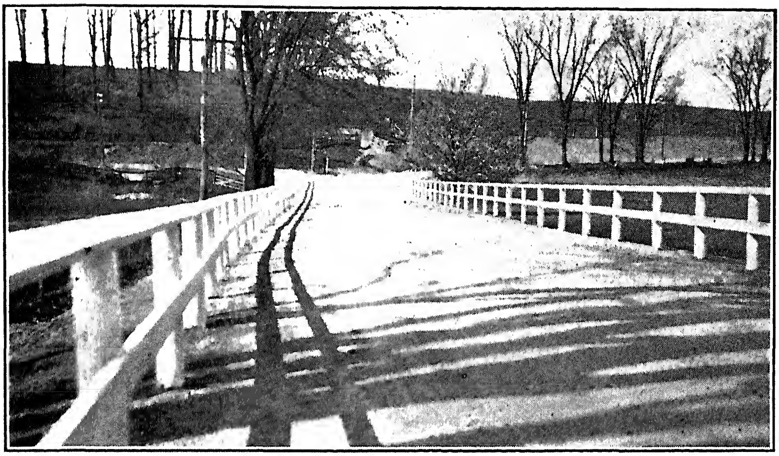


FIG. 37.—200 ft. radius curve in background on 3 per cent. grade. Serves traffic well. This road is a State Route in New York State carrying approximately 1500 vehicles per day in summer.

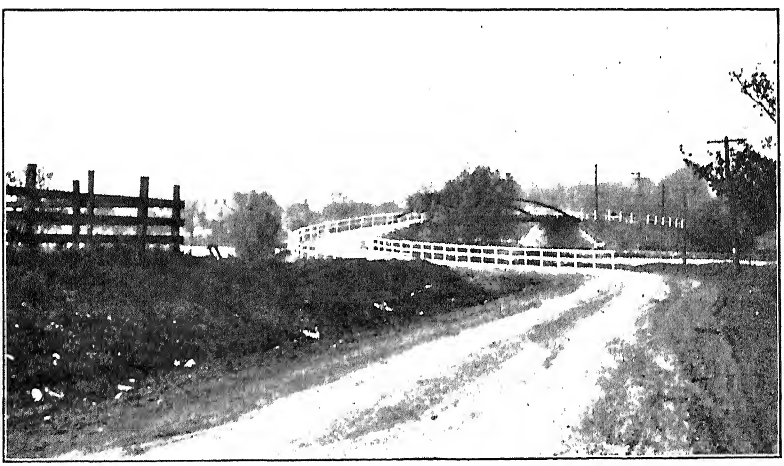


FIG. 37A.—Dangerous bridge approach alignment radius of curvature 75 ft. Alignment of this kind is very poor practice.

tractor trailer trains, 4 or 6 horse teams or the hauling of long timber sometimes limits the radius of a curve.

Rear Wheel Encroachment.—Under these conditions it is desirable to widen the section on the inside of the curve to provide clearance for the last wagon or the back wheels of a long rig as they work in towards the bank. To approximate roughly the distance that the last wheel works inside of the front guide wheel track we will assume that the rig has a stiff connection between the front and rear axle. This will give a result on the safe side as for a loosely coupled train or a special swinging rear axle much sharper corners can be turned.

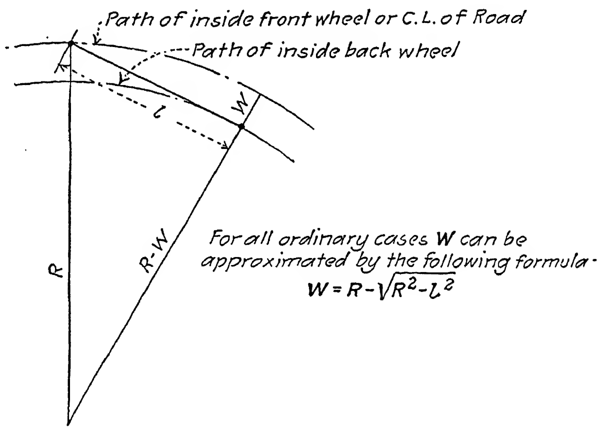


FIG. 38.

l = Length of rig between front and back axle.
R = Radius of circle travelled by inside front guide wheel.
W = Encroachment of back wheel in making curve.
(See table 18, page 140).

Mountain Road Alignment.—In mountain road location it is generally impossible to provide a safe sight distance as it would be prohibitive in cost. For such conditions considerable must be left to the care of the driver and the limitations of alignment are based more on the cost of construction than on the safety of traffic. Where long timbers are hauled over the road the foregoing table indicates the extra width or radius required.

Effect of Alignment on Grade.—On sharp curves it is desirable for the driver to have first-class control on the score of safety. An extremely sharp curve with a large central angle also reduces the hauling capacity of a six horse team by from 20 to 40 per

FIG. 39.—Example of first class side hill alignment. Also note liberal width of clearing to increase sight distance and to permit the sun to reach the road and melt snow.

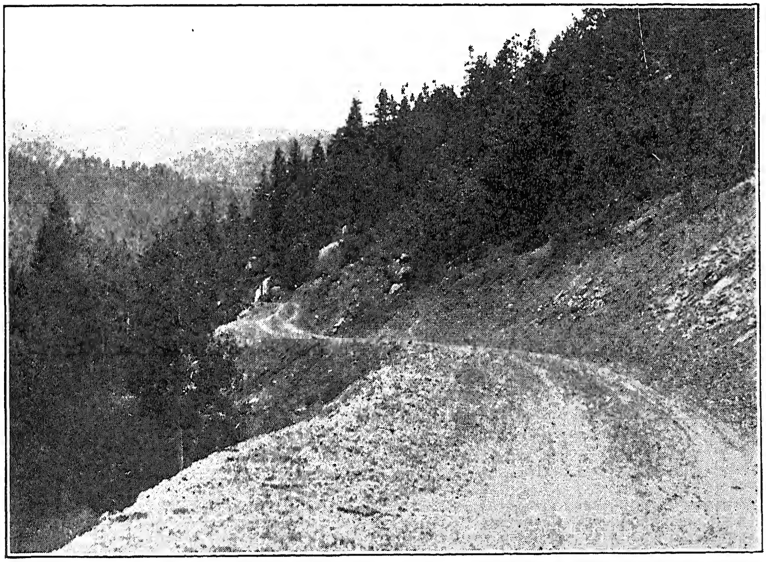


FIG. 40.—Example of ordinary side hill alignment.

Table 18.—Table of Approximate Encroachment of Rear Wheel Inside of Path of Front Wheel for Different Lengths of Rig and Different Radii of Road Center Line Assuming that the Central Angle of the Curve is Large Enough to Produce the Full Encroachment. This Generally Occurs when the Curve is Two or Three Times as Long as the Length of the Rig

Approx. radius of road center line in feet	Length of rig between front and rear axle in feet				
	10	20	30	40	50
	The values given below are the approximate distances in feet that the rear wheel runs inside of the front wheels.				
40	1.3	5.4	....	....	....
50	1.0	4.2	10.0	....	....
60	0.8	3.4	8.0	15.3	....
70	0.7	2.9	6.8	12.6	21.0
80	0.7	2.5	5.8	10.7	17.5
100	0.5	2.0	4.6	8.4	13.4
120	0.4	1.7	3.8	6.9	10.9
150	0.3	1.3	3.0	5.4	8.6
200	0.2	1.0	2.3	4.0	6.4
300	0.2	0.7	1.5	2.7	4.2
400	0.1	0.5	1.1	2.0	3.1

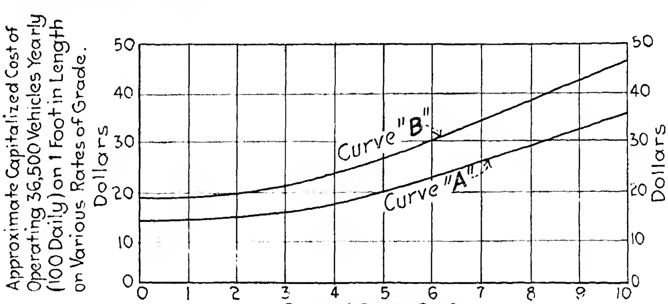
Note.—According to Droune the first pair of horses will occupy about 13 ft. ahead of the wagon and each additional pair 10 ft. more each. Wagons range in length from about 10 ft. for the bottom dump type to 50 ft. for trucks hauling timbers. The ordinary commercial 5-ton truck has a wheel base of 14 to 17 ft. Recent regulations limit the length from 20 to 30 ft. over all, and the total length of trailer trains to 90 feet.

cent. Considering both safety and team hauling it is therefore desirable to reduce ruling grades on sharp curves. These considerations have no practical value on mountain roads for curves having radii greater than 100 ft., but on sharper curves good practice recognizes this principle. Ordinary design uses radii of from 40 to 80 ft. on difficult switchback turns. For a 40 ft. radius the grade should not exceed 3 per cent. and for an 80 ft. radius 4 per cent. is a reasonable maximum. For high class roads in well settled districts at points where the sight distance is less than 350 ft. for commercial roads or 250 ft. for secondary state routes or local service roads the grade should not exceed 3 per cent.

Effect of Alignment on Motor Operating Costs.—Dangerous sharp alignment increases motor operating costs. It decreases normal speed and results in the needless use of second or low gear climbing and excessive braking on down grades. This action only occurs, however, on a very small percentage of the distance on a well designed road, viz.; at the danger points. That is if the alignment is safe for traffic it does not affect the operating cost. If it is dangerous for traffic it does affect the operating cost. As real danger is a more vital matter in the design than cost of operation, alignment design is controlled by the factor of safety and not by considerations of operating cost. That, is; danger will be eliminated if it is possible to do so and no consideration of cheaper operation would improve the alignment if the consideration of danger had not been sufficient to warrant it.

While there is no good data on the effect of alignment on operating cost, we have enough general data to state with reasonable assurance that if the radii of curvature are not sharper than from 250 to 300 ft. on the level or less than 400 to 600 ft. on grades and the sight distance is not less than 250 ft., that reasonable speeds need not be reduced on account of alignment and that motor operating costs are not materially affected. For sharper curvature and shorter sight distance the cost of operation is probably increased. How much we do not know, but purely as a matter of academic interest the author has modified the factors used in compiling table 12 for usual alignment, to conform with certain observed speeds on dangerous alignment. The following graph shows the result.

Curve "A" represents safe alignment. Curve "B" represents dangerous alignment.



Graph illustrating approximate effect of dangerous alignment on motor operation costs. (Time factor included). Curve "A" safe alignment (based on Table 12A, column I, page 100). Curve "B" dangerous alignment.

The general conclusion to be drawn is that motor operation is cheaper on good alignment and that if alignment can be made safe by steepening the rate of grade that a slight increase in rate will not add to motor operation costs over that required for the lower rate and poor alignment.

In conclusion we may say both from the standpoints of safety and operating costs, that it is desirable to design special service commercial roads for a sight distance of about 350 ft. and local service or secondary state routes for about 250 ft. Considerable expenditure is justified to obtain this requirement but large additional cost in order to further increase the sight distance is wasteful and poor engineering, particularly on roads of secondary importance. This caution is not a needless one as the author has recently heard designers excuse excessive profile and section grading on the score that it increased the sight distance beyond the 350 ft. limit. This limit is not necessarily proper or liberal enough for all conditions, but it seems good sense to arrive at some limit suitable for the road in question and then eliminate additional expenditure for an additional sight distance which may be fine to have if you can afford it, but which is really not necessary. The tendency of almost all departments working with large appropriations is to gradually increase the *fancy extras* which may not amount to much for one case but grow in number like a snow ball until you wonder why the cost of roads are going up and the mileage for your appropriations coming down.

Effect of Alignment on Construction Cost.—For high class road improvements in ordinary topography alignment does not have much effect on cost of construction. There is no particular object in long tangents and where an old road is being paved it is just as well to shift the center line slightly to keep on the old travelled way and take advantage of the old grading and any hard metalling that may have been placed in the past. Slight variations from the center of the right of way often save some grading expense and improve the character of the subgrade for the pavement.

In mountain road location, alignment is given careful consideration as it has a marked effect on cost. The radii are made as large as possible to fit the mountain side without excessive grading. On steep slopes the grade contour must be followed closely (see Figs. 41 and 42). There is no hesitation in using radii

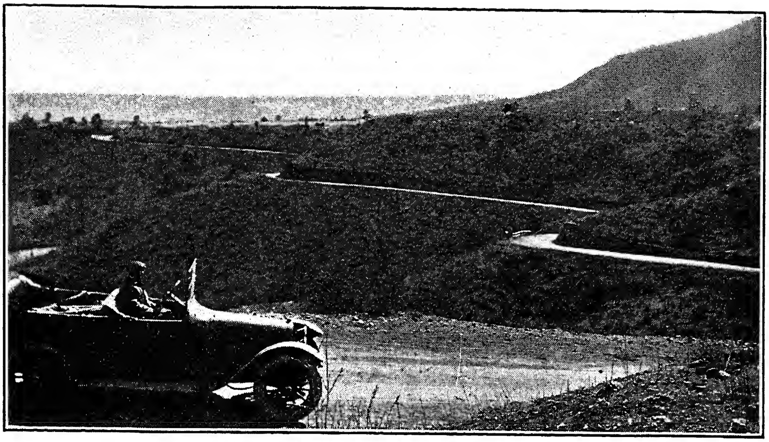


Fig. 41.—Alignment following grade contour closely (New Mexico).

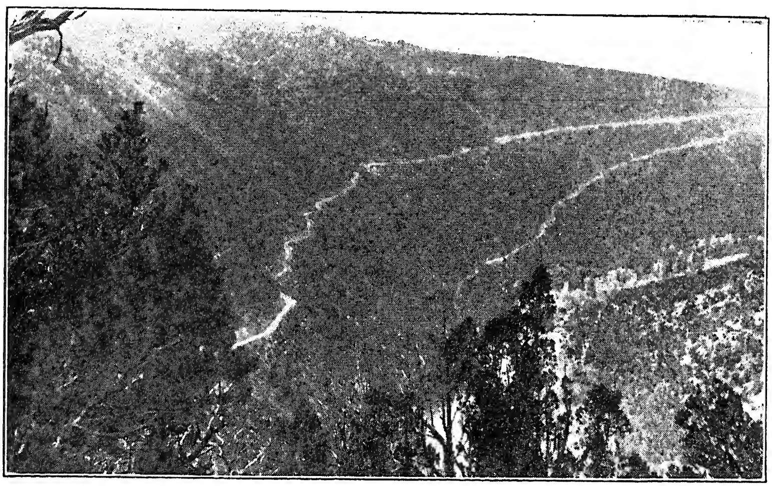


Fig. 42.—Example of crooked alignment on steep mountain slope. New road above and to the left. Old road below and to the right.

as sharp as 80 ft. at the head of gullies where the driver can see across the curve or a radius of 100 ft. on the outside curves around points where the sight distance depends on the radius. Even these limits are impracticable in very rough country where radii of 40 ft. are considered reasonable. All outside curves having a sight distance of less than 250 ft. should be posted with danger signs.

The arbitrary limitation of minimum radius has a large effect on cost. The following example will illustrate this point. These revisions were made by C. H. Chilvers on the Rabbitt Ears Pass Road in Colorado to show the effect of alignment on excavation.

The office method of plotting a good cheap alignment are described in detail in the third volume of this series.

RABBIT EARS ROAD, STATE OF COLORADO, SIDE HILL SECTION

Original design	First revision	Second revision
Length, 8.79 miles. Width of roadway, 16 ft. Maximum grade, 8 per cent. Grades flattened on switchback turns. Minimum radius 100 ft. First-class alignment throughout.	Length, 8.81 miles. Width, 16 ft. Maximum grade, 8 per cent. No grade compensation on curves. Minimum radius, 100 ft. First-class alignment but more curving eliminating many expensive tangents.	Length, 8.94 miles. Width, 16 ft. Maximum grade, 8.5 per cent. No compensation on curves. Minimum radius, 40 ft. Poor, crooked alignment carried to extremes.
Total amount of excavation, 91,000 cu. yd. First-class design but needlessly expensive.	Amount of excavation, 65,000 cu. yd. First-class design shows effect of careful, intelligent alignment engineering.	Amount of excavation, 38,000 cu. yd. Illustrates extreme effect of alignment on cost. From an engineering point of view there was no justification for this design for the topography in question.

NOTE.—On one switchback turn on this road a 100-ft. radius required 5000 cu. yd excavation and a 40-ft. radius 500 cu. yd. or one-tenth as much. Short radii are justified in isolated cases but their continuous use to save small amounts is poor practice.

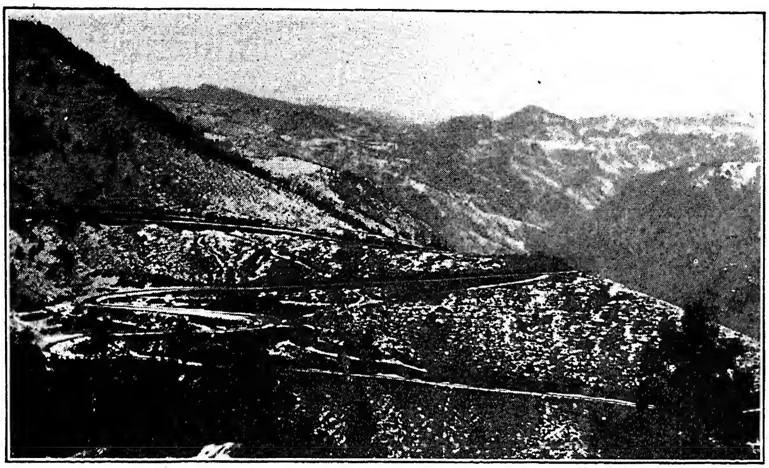


FIG. 43.—First class switchback design. Note flattening of grades on sharp turns.

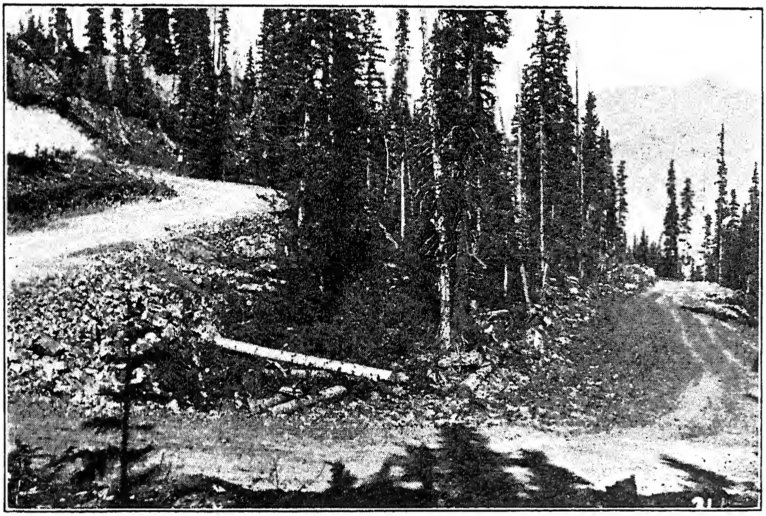


FIG. 44.—Poor switchback design, alignment too sharp. Grades not reduced on turns.

FIG. 45.—Excellent switchback layout on spur location. Note grade flattened on curve.

FIG. 46.—Retaining wall switchback construction.

Effect of Railroad Grade Crossings on Alignment and Grade.—Railroad grade crossings are sources of continual danger; they should be eliminated on all main routes. The discussion of subway and overhead eliminations is given in Volume III. If a grade crossing is necessary the best practice calls for a tangent crossing at least 400 ft. long 200 ft. on each side of the track. It is not advisable for the tangent to make an angle of less than 60° with the center line of the track. The approach grades should not exceed 5 per cent. and a level grade at least 50 ft. long should be provided on both sides of the track to permit the better control of the vehicle as it approaches the crossing.

Anyone owning an automobile is familiar with the dangerous element of driving where precautions of this nature are neglected.

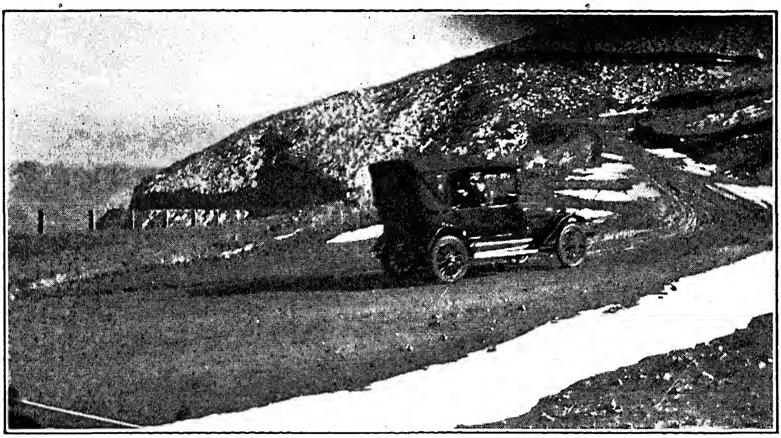


Fig. 47.—Example of flattening grade on switchback turn. Also note guard rail built of stone posts and wire cable.

Recommended Alignment Practice.—The following summary agrees with general current practice and can often be used without raising the cost beyond the bounds of reason. A summary of this nature is of course of only general value. Each case must be worked out on its own merits. Broad generalizations of detail requirements are dangerous if used indiscriminately.

Main Commercial Roads. (Well Settled Districts.)

Minimum sight distance	300 to 400 ft.
Minimum radius of curvature at right angle turns on level outside of villages where sight distance does not control	250 to 400 ft.
Minimum radius of curvature on steep grades or at the foot of such grades depending on the central angle where the sight distance is not the controlling factor	400 to 600 ft.

Ordinary Agricultural Roads. (*Local Service.*)

Minimum sight distance.............................. 200 to 250 ft.
Minimum radius of curvature at right angle turns on level outside of villages................................. 100 to 200 ft.
Minimum radius of curvature on steep grades where sight distance does not govern............................ 300 to 400 ft.

Mountain Roads.

No limitation on sight distance.
Warning signs used where necessary.
Minimum radius on steep grades....................... 100 ft.

Minimum radius in extremely rough country 40 ft. Grades not to exceed 3 per cent. for a 40-ft. radius and not to exceed 4 per cent. for an 80-ft. radius. Any grade up to 8 per cent. on a 100-ft. radius, although it is desirable not to exceed 5 per cent. on a 100-ft. radius curve with a large central angle.

Summary of Principles of Location.—Climatic, drainage and soil conditions govern a location in respect to avoiding bad snow conditions, flood areas, needless stream crossings, slide or swamp formations and excessive rock work. The general requirements of line and grade discussed in this chapter are summarized as follows: the various principles are repeated conversely under the headings of Grade, Alignment, Distance, Rise and Fall and Cut and Fill grade reductions.

First.—Reasonable maximum grades are essential. Recommended reasonable rates for various kinds of roads are given on page 116. The following treatment is allowable to get a reasonable maximum.

(*a*) Any expenditure necessary.

(*b*) Distance may be increased in order to get a reasonable maximum grade but should not be increased for a fixed rise to reduce grades *below* a reasonable maximum.

(*c*) Poor alignment may be used if necessary to get a reasonable maximum grade if funds are low but poor alignment should never be introduced to reduce grades *below* a reasonable maximum. Where poor alignment is necessary maximum rates must be reduced at the danger points (see page 140).

(*d*) For a fixed rise and distance, it is generally better to use a short length of reasonable maximum and the balance of the distance a low rate than to use a uniform moderate rate grade for the entire distance; this is not strictly in accord with the principles of cheap motor operation (table 12*B*, page 104) but the net practical results are generally better. This means that if a road is running up a valley on an easy grade and must leave the bottom land and climb on a side hill location to reach a pass that it is generally better to make the climb as short in distance as possible as a side

hill location usually introduces poor alignment and generally increases the excavation per mile over a valley location.

Second.—Alignment should be made as safe as possible considering the funds available. Safety of traffic governs alignment practice. Cost of traffic operation has no practical effect.

(*a*) Good alignment should never be sacrificed to reduce grades below a reasonable maximum. For safe alignment practice (see page 147).

(*b*) Good alignment may be sacrificed to get a reasonable maximum but this condition necessitates the reduction of grade at the danger points. (See page 140.)

(*c*) Improved alignment warrants increased distance only when danger is eliminated. Increased distance is not warranted merely to make an easy curve easier.

(*d*) It is better to use a steeper grade (up to a reasonable maximum) with good alignment than to use poor alignment and a lower rate.

(*e*) Exceptionally good alignment (practically straight) may in some cases warrant an increase in the reasonable maximum grade above the rates recommended on page 116. This modification would not however apply unless it was impossible to locate and grade the lower rate location so that the sight distance on it was at least 250 ft.

(*f*) An alignment and grading design which results in a sight distance of 250 to 350 ft. is safe and desirable but large expenditures to still further increase the sight distance must be used with caution unless the funds are practically unlimited. Increase in maximum grade above the recommended maximum in order to increase sight distance above 250 to 300 ft. is rarely warranted.

Third.—Short distance is desirable provided considerations of safety, rise and fall, or reasonable maximum grades do not modify the conclusions.

(*a*) Distance may be increased to reduce danger by better alignment at bridge approaches, railroad crossings, or to avoid difficult topography. Recommended minimum radius of curvature are given on page 147.

(*b*) Distance should be increased to get a reasonable maximum for a fixed rise but rarely to reduce the grade below a reasonable maximum for a fixed rise.

(*c*) Distance should never be increased to reduce rise and fall on grades of 2 per cent. or less.

(*d*) Distance may be increased to reduce rise and fall on grades over 2 per cent. (use table 12*B* for comparisons of this kind) but for grades not exceeding the maximum it is rarely desirable to increase distance unless a noticeable rise and fall can be eliminated by a small additional distance. *For ordinary easy rolling topography the principle of the straight line location is generally sound.*

Fourth.—The elimination of needless rise and fall is desirable modified by certain conditions.

(*a*) The elimination of rise on steep grades is desirable. Distance may be increased to accomplish this provided the disadvantage of increased distance is balanced against the value of less rise (see table 12*B*, page 104).

(*b*) The elimination of rise on grades of 2 per cent. or less is of no value from a practical standpoint.

(*c*) Adverse grades may be used to eliminate dangerous alignment or shorten distance provided the shorter distance is of more value than the disadvantage of the extra rise (see table 12*B*).

Summary of Cut and Fill Grade Reductions.—Grade reductions by cut or fill assume that the road location is fixed for some reason and that further improvement must be by cut or fill. The distance is always fixed. *Reasonable maximum grades are essential.*

(*a*) For a fixed rise there is no practical advantage in reducing the rate of grade below a reasonable maximum.

(*b*) Reduction of total rise and fall on steep grades is desirable.

(*c*) Reduction of rise and fall on light grades has no practical advantage.

(*d*) The use of short adverse grades of 2 per cent. or less on a long climb has no practical disadvantage.

The sources of justifiable economy in cut and fill design lie in the use of the short maximum in connection with the long ruling grade and the use of a rolling grade profile for all intermediate rates.

The application of these principles in conjunction with the "spotting method" of profile design generally results in a satisfactory road at a moderate grading cost. The violation of these principles of location and cut and fill profile design occur quite frequently.

Conclusion of Chapter.—The considerations discussed in this chapter govern the engineering field location and in conjunction with the variation in road cross section determine the effectiveness and economy of the grading design. The methods of their practical application are taken up in the third book of this series by means of actual designs worked out in detail and modified by systematic criticism.

Grades and alignment are fundamental permanent features of highway improvement. There should be no hesitation in spending all the money that may be required to get satisfactory results for average traffic but extreme refinements of location may will well be avoided if they materially increase the cost.

CHAPTER V

CROSS SECTIONS OF RURAL ROADS, WIDTHS OF PAVEMENT, RIGHT OF WAY AND CLEARING

The shape and width of road cross sections have considerable effect on the safety and convenience of the highway for traffic and they also affect the economy of grading design. It is desirable to obtain features that are fundamentally required for the satisfaction of traffic but it is also desirable to avoid arbitrary standardization which adds materially to the cost without any adequate benefit. The problem of sections can be summed up as the determination of the minimum widths of grading, pavement, etc., the minimum depth of surface ditches in cut and variations in shape and width that will serve the present traffic requirements.

At the time a road is improved, right of way should be acquired of such a width that it will permit the future widening of section, pavement, etc. Liberal right of way can be obtained more easily during the first stages of road improvements than at a later time when the land is worth more and buildings have been erected close to the road. That is right of way considers the future requirements of the road but grading widths can only reasonably consider the requirements of existing traffic.

Sections.—Sections can be considered from the standpoints of Safety, Convenience and Economy.

Safety requires a grading shape that permits the rig to use any part of the road from ditch to ditch without overturning or if this is not possible various expedients such as the one way crown, banking on curves, guard rail or wall protection will very materially help the traffic. Safety requires a liberal sight distance which on sharp curves can be obtained by "Daylighting" the section (see Figs. 35 and 36, page 136).

Convenience requires sufficient width for vehicles to pass at any point in ordinary topography and provides special turnouts at short intervals on Mountain Roads. It also calls for crown and shoulder slopes that permit driving without an uncomfortable side tilt to the rig.

Economy of grading calls for various combinations of widths, ditch depths, back slopes, etc. which most nearly fit the natural conditions at all points. That is the section must be flexible.

It is, perhaps, best to develop the discussion of sections and pavement widths first for the high class road in ordinary topography and second for pioneer roads in mountainous conditions.

High Type Roads (Premises of Design).—The points to be considered in the development of a normal section are:

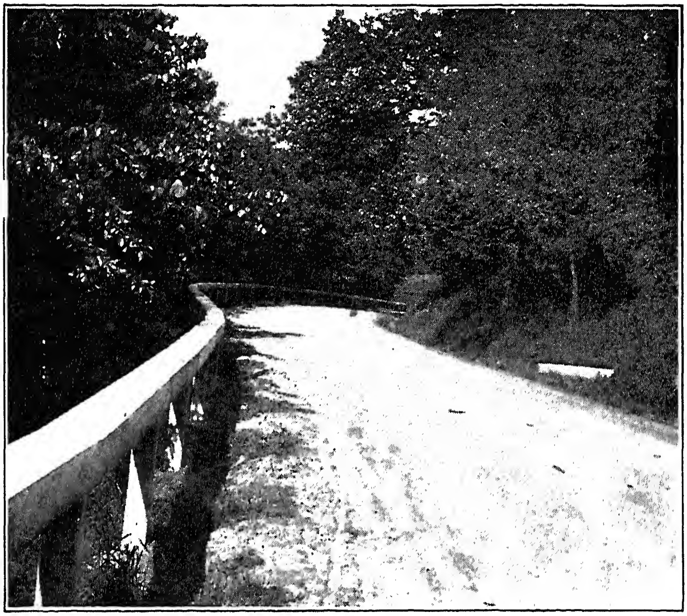


FIG. 48.—Banked curve on high class road protected by substantial concrete guard rail.

1. What is a safe driving slope?
2. What is a comfortable driving slope?
3. What pitch is required to drain different surfaces?

These factors determine the shape of the section.

4. What is the commonly used width and the maximum width of the travelled way?

These factors determine the width of pavement and shoulder.

5. What is the minimum allowable depth of surface ditch?
6. What are stable slopes for cut and fill outside of the limits of the travelled section?

These factors affect the economy.

The first three questions have been pretty well settled by current practice; the last three are not so well defined. We will, however, assume the following premises which can be modified for special conditions:

1. Three inches to 1 ft. or 4:1 is the maximum safe driving slope.
2. One inch to 1 ft. or 12:1 is the maximum agreeable driving slope.
3. One inch to 1 ft. or 12:1 is the minimum slope at which an earth shoulder will shed water without too much maintenance. Three-fourth inch to 1 ft. or 5/8 in. to 1 ft. is a satisfactory crown for a single track Waterbound Macadam Road and 1/2 in. to 1 ft. is a satisfactory crown for a double track Waterbound Macadam pavement. Three-eighth inch or 1/2 in. to 1 ft. is a satisfactory crown for double track Bituminous Macadam pavements or waterbound macadam treated with tar or asphalt flush coats. One-fourth inch or 3/8 in. to 1 ft. serves very well on rigid pavement types such as brick, concrete, sheet asphalt, etc. Circular arc or parabolic crowns are more satisfactory than the straight line section for the pavement proper.
4. The width of roadbed subjected to hard wear by traffic on the lighter traveled roads (single track roads) ranges from 8 to 10 ft. and on double track roads from 14 to 17 ft. The maximum width of roadway subjected to some wear by traffic turning out to pass ranges from 18 to 22 ft.
5. The minimum ditch depth below crown grade depends on keeping the longitudinal surface water outside of the travelled way and is rarely less than 10 in.; it depends largely on the amount of surface water that must be cared for.
6. The stable cut and fill slopes depend on the climate and the material and range from 1/4:1 to 4:1.

Before proceeding further, it will be just as well to discuss a little more fully, items 4, 5 and 6.

Widths of Travelled Way (Item 4).—The width of roadway carrying the greater portion of the travel and the maximum widths when rigs turn out to pass are not well established. They are affected by the volume and speed of traffic, the pavement crown, and the width of vehicles.

Effect of Crown.—Crown has a marked effect on width of heavy travel. A crown such as 3/4 in. to 1 ft. or 1 in. to 1 ft. tends to concentrate the traffic in the center and is a detriment on a heavy traffic road. With crowns of 1/2 in. to 1 ft. or less there is no tendency to concentrate. For single track macadam or gravel roads where the traffic tends to stay in the center of its own accord on account of infrequent passing of rigs a fairly heavy crown is desirable as it is easier to maintain. On double track roads a crown of 1/2 in. to 1 ft. or less should be used both on account of

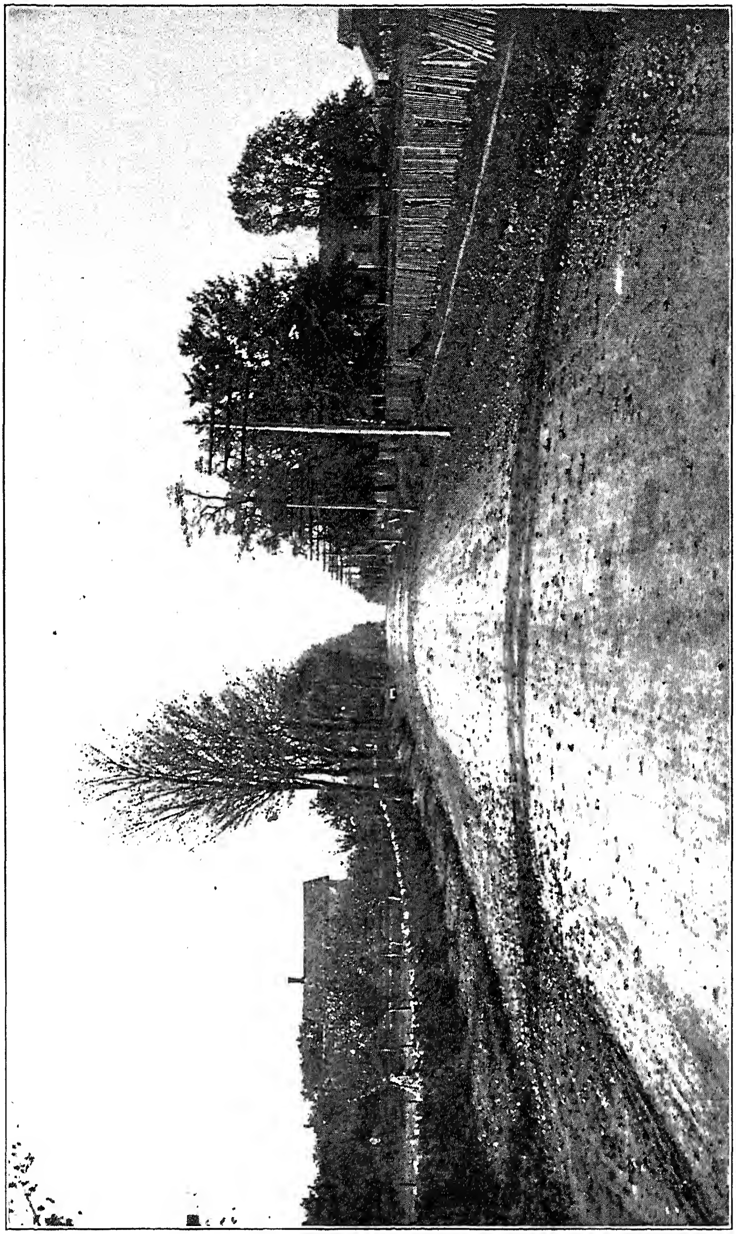


Fig. 49.—A safe and pleasing road section.

convenience to traffic and to more evenly distribute the wheel wear (see premises of design, page 153).

Widths Actually Used.—Probably the most systematic record of widths actually used by traffic can be found in the reports of the Massachusetts Highway Commission reports during the years 1896 to 1900. These results were obtained under the old horse drawn traffic conditions and do not apply closely for the conditions of today. They are included in connection with this discussion to illustrate the change which modern automobile traffic has made in width requirements on the heavier traffic roads. They, however, show a general relation between areas of light and heavy traffic on the lighter travelled agricultural roads.

Table 19 gives the results on a few roads showing the form used and the variations from year to year. The footnote gives a summary of 160 roads and shows the results much better than by printing the table in full.

Stated briefly the widths subjected to continuous wear on unimportant roads ranged from 8 to 10 ft.; on well travelled roads 10 to 14 ft. and in unusual cases 14 to 16 ft. The maximum widths for turn out traffic varied from 12 to 14 ft. on side roads and 17 to 18 ft. on the main roads.

Modern traffic has changed conditions on the main roads but does not greatly affect these figures on the lighter travel roads up to about 300 vehicles per day. The author has measured similar widths on New York State main roads and found that they checked the widths of heavy travel of 14 to 16 ft. but that the maximum turn out widths were more, running from 20 to 22 ft. This can be explained by the increase in automobile traffic which on account of its higher speed requires more room in passing.

Even a single track pavement should have ample shoulder width to permit traffic to turn out and pass easily. That is the total width of pavement and driving shoulder no part of which should have a slope of more than 1 in. to 1 ft. is practically the same for single or double track roads.

Effect of Vehicle Widths.—The width of modern vehicles has a decided bearing on double track pavement and shoulder turnout widths. The ordinary pleasure automobile is about 5 ft. 6 in. wide. The ordinary truck about 7.0 ft. wide with a wheel gauge of about 6.0 ft. Traffic regulations generally limit the width of vehicles to 96 in. except traction engines which may

be 110 in. The outside wheel of any rig ought to be about a foot inside of the edge of the driving shoulder and there ought to be at least a foot and a half clearance between passing vehicles. on straight alignment and at least three feet on sharp curves.

TABLE 19.—SHOWING WIDTHS OF TRAVELED WAY

Town or City	County	ft. Width of macadam	Maximum width of travelled way				Width of commonly travelled way			
			1896, ft.	1897, ft.	1898, ft.	1899, ft.	1896, ft.	1897, ft.	1898, ft.	1899, ft.
Athol	Worcester	17	16	16	20	18	10–12	12	14	14
Barre	Worcester	15	.....	13	14	14	.....	9	7	8
Bedford	Middlesex	15	.....	12	15	15	.....	8	10	9
Chicopee	Hampden	20	.....	20	20	20	.....	12	12	13
Dalton	Berkshire	15	20	20	21	16–21	20	16	18	12–18
Fitchburg (W.)	Worcester	15	15	14	18	18	10	10	15	14
Huntington	Hampshire	15	9	11	11	12	7	8	9	8
Lincoln	Middlesex	15	15	15	15	15	10	9	10	10
Marshfield	Plymouth	15	14	12	11	12	8	9	7	7
North Adams	Berkshire	15	10–12	13	14	15–20	8–10	9	10	12
Orange	Franklin	17	16	16	20	20	10–12	12	15	15
Taunton	Bristol	15	20	20	15	18	10–15	10	8	7–12

Width of traveled way on 160 roads in Massachusetts, measured during the years 1896, 1897, 1898, and 1899, and printed in the report of the Massachusetts Highway Commission for 1900.

The width of stone on these roads is given as 15 ft. wide on 130, 12 ft. wide on 3, and 10 ft. wide on 2. It should be remembered that the stone is put on very much thicker in the middle than at the edges.

The maximum width of traveled way as measured was as follows:

9 ft. wide on 2 roads	18 ft. wide on 23 roads
10 ft. wide on 6 roads	19 ft. wide on 1 road
11 ft. wide on 2 roads	20 ft. wide on 10 roads
12 ft. wide on 28 roads	21 ft. wide on 10 roads
13 ft. wide on 8 roads	22 ft. wide on 1 road
14 ft. wide on 23 roads	24 ft. wide on 2 roads
15 ft. wide on 30 roads	25 ft. wide on 4 roads
16 ft. wide on 8 roads	26 ft. wide on 1 road
17 ft. wide on 1 road	33 ft. wide on 1 road

The width of commonly traveled way as measured was as follows:

7 ft. wide on 12 roads	14 ft. wide on 8 roads
8 ft. wide on 17 roads	15 ft. wide on 13 roads
9 ft. wide on 25 roads	16 ft. wide on 2 roads
10 ft. wide on 32 roads	18 ft. wide on 4 roads
11 ft. wide on 10 roads	20 ft. wide on 2 roads
12 ft. wide on 30 roads	22 ft. wide on 1 road
13 ft. wide on 3 roads	25 ft. wide on 1 road

On this basis roads having much truck traffic would require a minimum turn out width of about 18 ft. which is probably about right for the minimum width of rigid pavement on such roads but hardly liberal enough for total shoulder width to take care of exceptional cases which occur more or less frequently.

Recommended Practice.—The available data obtained from observations on actual traffic movement indicates that a minimum turn out width of 20 ft. is desirable on single track side roads, 22 ft. on secondary double track roads and 24 ft. to 26 ft. on main double track special service roads. For a triple line of traffic 34 ft. and a four track road 42 ft.

From this data it appears that modern practice on single and double track roads requires a width of solid pavement of from 10 to 20 ft. and a total driving width including shoulders of from 20 to 26 ft.

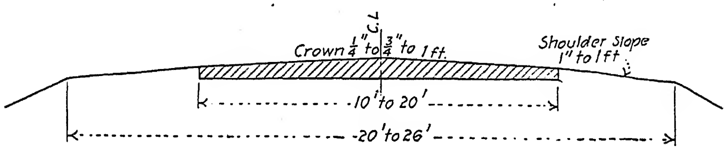


Fig. 50.

We have now practically developed a standard for the portion of the section used for driving (Fig. 50). The pavement that is to carry the heavy traffic has a specified crown for each variety and ranges from ¼ to ¾ in. to 1 ft. The shoulder slope from the edge of the pavement to the limits of the driving width (20 to 26 ft.) has a slope of 1 in. to 1 ft. or possibly ¾ in. to 1 ft. That is, the shape of the driving portion of the normal section is fixed. The flexibility of the section depends on the portion outside of this driving width.

The function of the extra width is to keep the longitudinal drainage of surface water beyond the portion used for driving. To do this we are limited to a minimum slope of 1 in. to 1 ft. to insure transverse drainage and a maximum of 3 in. to 1 ft. on the score of safety. It is by the good judgment of the designer in using various slopes between these limits and various widths and depths of ditches, combined with the possibilities of different grades that the economics in earthwork are affected and at the same time the design is made appropriate to the local conditions.

Depth of Ditches (Item 5).—The author's experience indicates that an open ditch does not have much effect on ground water; that its part in the design is to drain the surface water and that if ground water is encountered underdrains must be used. These conclusions have been borne out in practice and are advocated by many engineers notably Irving W. Patterson of Rhode Island

who has had unusual success with his drainage and foundation designs. The principle we wish to emphasize is *that deep surface ditches below the elevation of the bottom of the pavement foundations are useless. Deep ditches are not only useless but dangerous and the best practice calls for the least depth of ditch that will handle the surface water.*

A great many road men seem to feel that a deep open ditch really helps drain the subgrade but as stated the author has

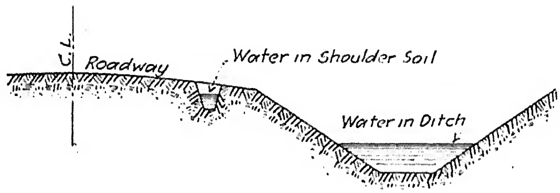


Fig. 51.

never been able to prove by cases where foundation failure occurred that the depth of surface ditch had any well defined bearing on the matter provided the ditch carried away the surface water promptly. Some soils have a strong capillary action and the water works up through them. In impervious soils such as clay a surface ditch 15 ft. from the center line can not have much drawing action as in numerous cases small holes dug in the roadbed (Fig. 51) fill with water at a much higher elevation than the side ditch.

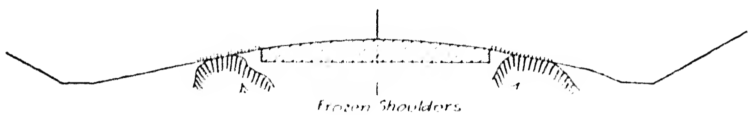


Fig. 52.

In many instances in the northern states the ground under the pavement proper thaws out before the shoulder material which is protected by a sod coating and the following result is obtained (Fig. 52). Under these conditions the moisture in the center is held even in porous soils. As a matter of fact all pavement foundation design must be predicated on the assumption that even with the best drainage schemes the subgrade will at times soften somewhat and for this reason the use of deep ditches which are inconvenient

to traffic and which increase the grading cost are not in as much favor as in the past.

Frequent culverts are desirable to rid the ditches of excess water. It should be remembered that road ditches are to protect the road and not furnish farm drainage and that deep farm ditches should be kept away from the road section.

The following Rhode Island standard grading sections show the use of the shallow 12 in. ditch which is advocated wherever a small amount of surface water is expected.

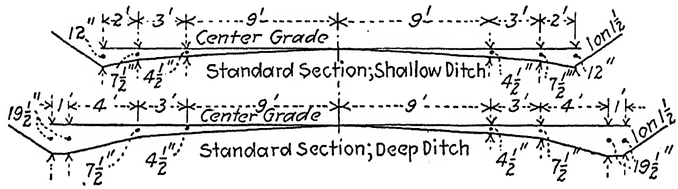


FIG. 53.—Rhode Island standard grading sections.

The following section (Fig. 54) represents a good typical minimum width and minimum ditch depth grading section for single or double track roads which has been proved by practice to be satisfactory where small amounts of surface water are encountered. This section results in about the least feasible amount of cut and fill in grading design for light cuts and fills. The approximate

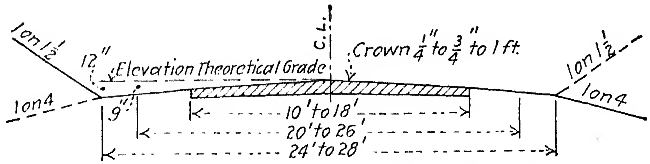


FIG. 54.—Typical minimum width grading section.

carrying capacity of ordinary road ditches and the limitations of use of the shallow and medium road ditches are discussed under "Longitudinal Drainage," p. 262.

Effect of Grading Width on Cost.—The width of grading from ditch to ditch has a distinct effect on cost but no general relation can be established for the ordinary road improvement where an old road forms the basis for the new grading. Two examples are given to show the value of reasonable reduction in sectional widths.

1. Indian Falls-Corfu Road in New York State

Length 1.85 Miles

No change in profile
No change in ratio of cut to fill

Original Design	Revised Design
Width of macadam, 14 ft.	Width of Macadam, 14 ft.
Width of section, 30 ft.	Width of section, 24 ft.
Depth of ditch, 18 in.	Depth of ditch, 14 in.
Original estimated excavation, 7500 cu. yd.	Revised estimated excavation, 5200 cu. yd.

This change in section alone resulted in a saving of 2300 cu. yd. excavation or at the rate of 1240 cu. yd. per mile, or in money about $600.00 per mile with excavation at $0.50 per cu. yd.

2. Pittsford-North Henrietta Road in New York State

Length, 2.67 miles

Original Design	Revised Design
Width of section, 30 ft.	Width of section, 24 ft.
Depth of ditch, 18 in.	Depth of ditch, 12–14 in.
Ratio of cut to fill, 1.35 per cent.	Ratio of cut to fill, 1.25 per cent.
Maximum grade, 5.0 per cent.	Maximum grade, 5.0 per cent.
Profile—Designed with straight instead of rolling grades and tangents of 100 ft. between vertical curves.	Profile—Rolling grades and reverse vertical curves used.
Original estimated excavation, 11,450 cu. yd.	Revised estimated excavation, 6620 cu. yd.

A saving of 4820 cu. yd.; 1800 cu. yd. per mile, or in money, approximately $900.00 per mile.

The revised design on this road is a good example of what can be saved by the use of a section that fits the conditions, a rolling grade, and a ratio of cut to fill that we have found from experience to be sufficient.

Stable Cut and Fill Slopes.—Economy of design and maintenance is affected by the selection of reasonably stable slopes. For the class of grading usually encountered on roads built in ordinary topography their effect on construction cost is not great and they do not generally receive much attention but for mountain roads cut and fill slopes are an important consideration in the design and their effect on cost are worth considering.

Table 23, page 200, shows the effect in detail of various cut and fill slopes on yardage of the ordinary sidehill mountain road sections. To illustrate the point we will quote one typical case for say an ordinary double track section (S-14), Table 23.

of even one foot in width makes a large difference in cost when applied to a State System and the most suitable widths are open to argument.

Type of pavement	Assumed cost per sq. yd.	Cost per ft. width 1 mile long
Brick	$4.50	$2700
Asphalt concrete	3.50	2100
Cement concrete	3.20	1920
Penetration bituminous macadam	2.20	1320
Waterbound macadam	1.80	1080

Widths in Use.—Blanchard's Handbook states that in Austria government roads have a pavement width of about 21 ft. and provincial roads 14 to 16 ft. In northern France many of the main roads have a 15 ft. width of pavement proper with 2½ ft. of stone shoulders on each side making a total of about 20 ft.

The French national roads have a metalling width of about 23 ft. and the English main roads run from 16 to 22 ft.

In this country there are two sets in general use 10, 12; 15 and 18 and 12, 14, 16 and 20. In the author's opinion the first will serve satisfactorily and is naturally more economical using the 10 or 12 ft. width with special stone shoulders if desired for secondary local service roads; the 15 ft. width with first class special stone shoulders on the main double track local service roads and the 18 ft. width for rigid pavements on double track special service roads. A 20 ft. width near large cities adds materially to the comfort and ease of traffic on commercial roads and is probably justified if the funds are available. For each additional line of traffic add about 9.0 ft. provided the traffic regulations permit a 96 in. width of truck body.

There are two ways of solving the problem. The first is to build the strong metaling just wide enough to comfortably take the heavy traffic and if the natural shoulder material is not suitable treat the shoulders to a width of from 16 to 22 ft. with gravel, crusher run or 2½ in. stone filled and rolled or if desired puddled or tarred making them suitable and wide enough for the turnout traffic. Referring to the widths actually used by hard traffic previously discussed this method results in the 10 or 12 and 15 ft. widths. The second way is to make the full depth of metaling just wide enough to allow traffic to pass by careful

driving not giving the shoulders any special treatment. This method results in the 14 ft. width on unimportant roads. The 16 ft. width is harder to justify as on the main roads it is wider than necessary for moderately heavy local service travel and too narrow for automobile "turnout traffic." Where rigid pavements are needed 18 ft. is the minimum width recommended as

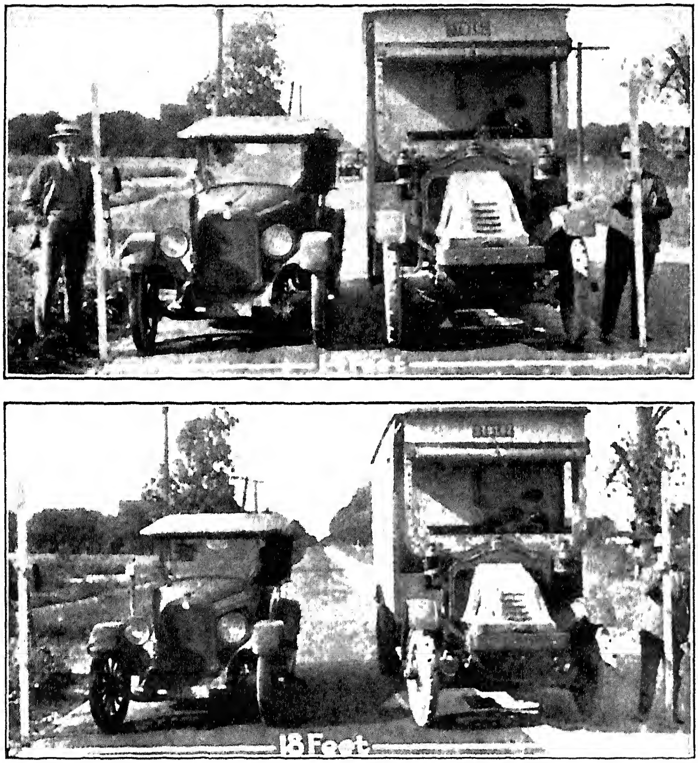


FIG. 56.—Illustrates normal traffic clearance, on different pavement widths.

dangerous ruts develop along the edges where the 15 or 16 ft. width is used and even with careful maintenance this condition can not be avoided under heavy truck traffic on special service roads.

While shoulder treatment is desirable on the main travelled roads its importance on side roads should not be overestimated. A record of a trip from Albany to Binghamton, New York, showed that rigs were passed on an average once every 4 miles outside of villages. From this it would seem that for secondary roads of this character shoulder treatment is not worth while even

for the 12 ft. width unless particularly bad soil conditions are encountered. Where the 10 ft. width is used solid turnouts should be provided at frequent intervals to allow heavily loaded vehicles to pass.

In the writer's opinion 10 or 12 ft. should be used in preference to 14 ft. on side roads where the shoulder material is good and that 12 or 14 ft. with special shoulders if desired should be used where the shoulder material is poor. On the main local service roads a 15 ft. macadam is as satisfactory as the 16 ft. width and is cheaper under all conditions as the 16 ft. width does not overcome the necessity for a good shoulder. Where rigid pavements are required 18 ft. is the minimum width that will give satisfaction on double track roads.

Effect of Curvature on Pavement Width and Shape.—Sharp curves modify the width and crown of road pavements. Width is increased to provide greater clearance between fast moving vehicles (approximately 3 ft.) and also to take care of the back wheel encroachment of long wheel base rigs (see Table 18, page 140). The crown is usually changed to a "banked" or "one way crown" similar to superelevation of a railroad curve to make it easier to take the curve at reasonable speed and to reduce the side thrust of the wheels on the pavement and the danger of skidding.

Amount of Widening.—Current practice based on experience, which is the safest guide, favors the following widths on curves.

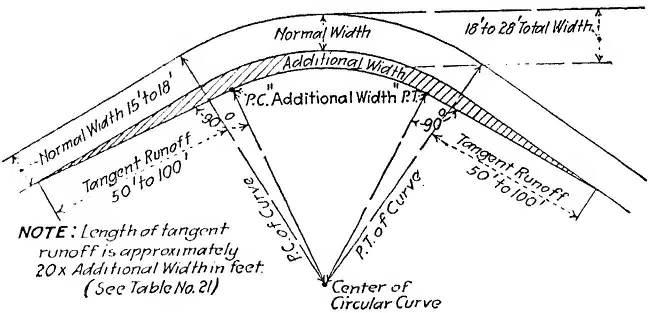


FIG. 57.

On local service roads use (Table 21). On special service commercial roads use Table 21A. The pavement is widened on the inside of the curve. The full widening is carried around practically the entire curve from close to the P. C. to a point

near the P. T. (see Fig. 57). The tangent runoff to the normal width is made from 50 to 100 ft. long to look well according to the judgment of the constructor. This is an easy layout to make in the field and serves the traffic satisfactorily. The widths given in Table 21 permit two outfits, each consisting of a 7 ft. width truck with one trailer, to pass easily. Trucks 8 ft. wide without trailers can also pass easily. The widths given in Table 21A permit comfortable passing of 8 ft. trucks with one trailer.

TABLE 21.—PAVEMENT WIDTHS ON CURVES OF LOCAL SERVICE ROADS AND SECONDARY STATE ROUTES. (SEE FIG. 57)

Radius of road center line, ft.	Total pavement width on curves for a double track road (local service), ft.	Length tangent runoff in ft.
50	29	100
75	25	100
100	23	100
150	22	90
200	21	90
300	20	80
400	20	80
500	19	70
600	18	50

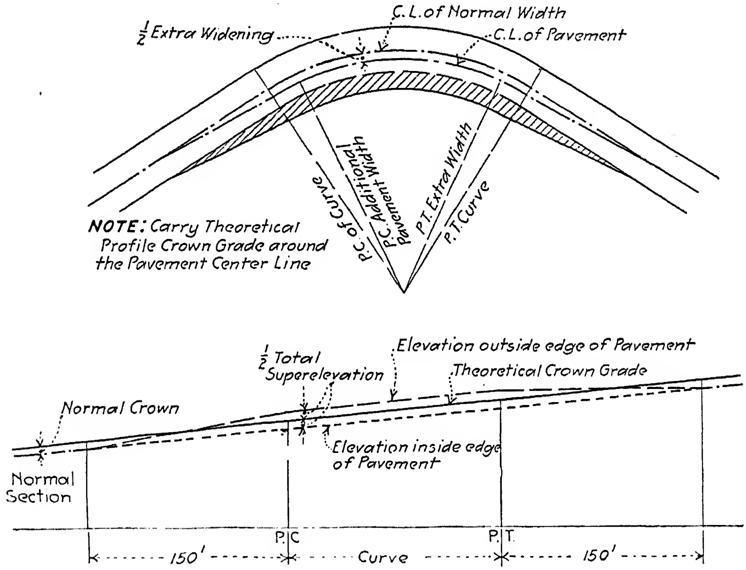
NOTE.—Normal pavement width (15 to 18 ft.) used on all curves having a radius greater than 600 ft.

TABLE 21A.—PAVEMENT WIDTHS ON CURVES OF SPECIAL SERVICE COMMERCIAL ROADS

Radius of road center line in ft.	Total pavement width in ft.	Length tangent runoff in ft.
100	25	100
150	24	90
200	23	90
300	22	80
400	22	80
500	21	70
600	21	70

NOTE.—Normal pavement widths of 18 to 20 ft. used on all curves having a radius greater than 600 ft.

Amount of Superelevation.—Superelevation of the pavement can not be figured as there are too many variable factors. Cars take easy curves at higher rates of speed than the sharper curves which fact tends to equalize the bank crown. The pavement must not be tipped enough to make it dangerous for slow moving vehicles. The full superelevation is carried around the entire curve from P. C. to P. T. and reduced to the normal crown at



Profile of Transition from Normal to Banked Section

FIG. 58.

points from 100 to 200 ft. along the tangents from the P. C. or P. T. The normal grade is carried around the center line of the pavement and the outer edge raised and inner edge lowered to produce the required side tilt (see Fig. 58).

Current practice favors the following one way crown slopes on curves.

TABLE 22.—TABLE OF CROWN SLOPES ON BANKED CURVES

RADIUS OF ROAD CENTER LINE IN FEET	RECOMMENDED UNIFORM CROWN SLOPE
50– 200	1¼ in. to 1 ft.
200– 500	1 in. to 1 ft.
500– 800	¾ in. to 1 ft.
800–1000	½ in. to 1 ft.

NOTE.—Curves having a radius of over 1000 ft. are not generally banked.

Current Practice in Standard Sections.—The following Standard Sections give an idea of current practice.

Fig. 59.—Pennsylvania.	Fig. 63.—Alabama.
Fig. 60.—New Jersey.	Fig. 64.—Maine.
Fig. 61.—Indiana.	Fig. 65—Wyoming.
Fig. 62.—California.	Fig. 66.—West Virginia.

Figs. 67–69.—Recommended Practice.

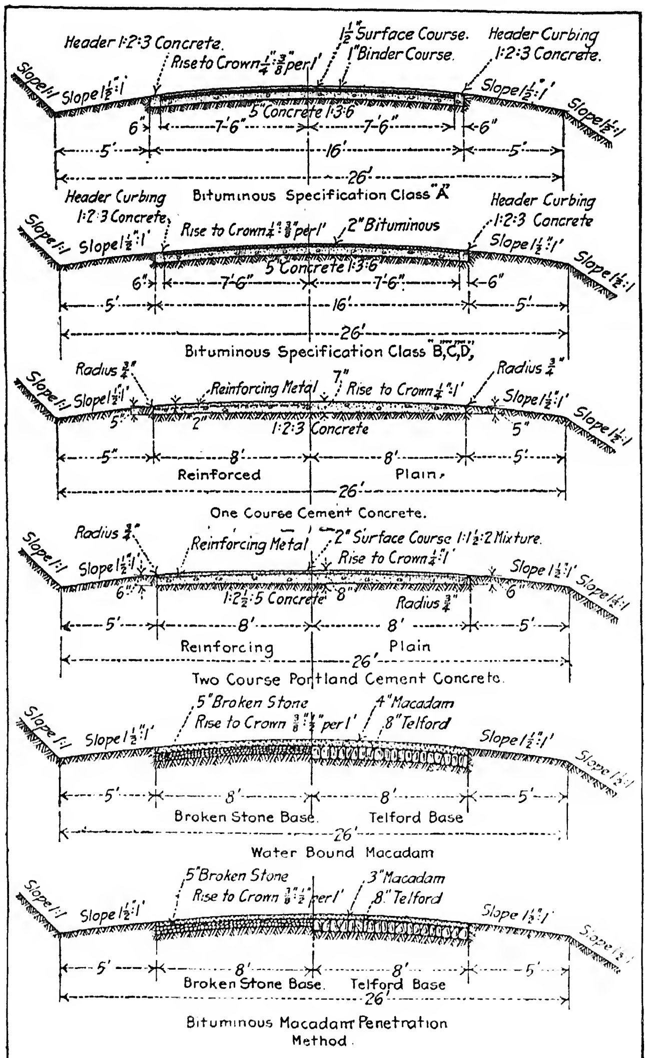


Fig. 59.
State of Pennsylvania.

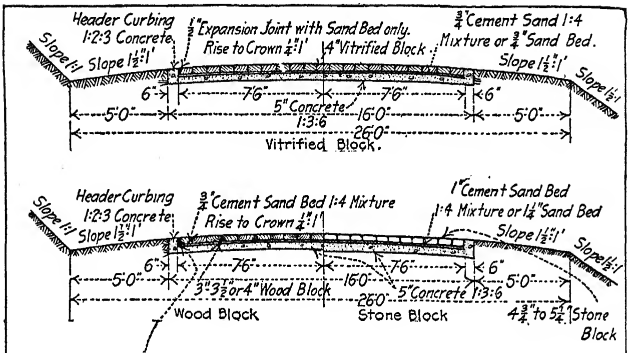


Table Showing Distance below Center for each ⅛" Width Point for any Crown 2" to 8"

Curb.	2"	3"	4"	5"	6"	7"	8"
⅛ Width	1⅛"	1⅜"	2¼"	2¾"	3⅛"	3⅞"	4½"
¼ "	½"	¾"	1"	1¼"	1½"	1¾"	2"
⅜ "	⅛"	⅛"	¼"	¼"	⅜"	⅜"	½"
Center.	0"	0"	0"	0"	0"	0"	0"

Table Showing Additional Widths of Surfacing on Curves of Different Radii, and Superelevation per Ft. Width

Radius of Ctr. Line, Ft.	Additional Width
30	8.0
40	7.0
60	6.0
80	5.0
100	4.5
120	4.0
140	4.0
160	3.5
180	3.5
200	3.0
220	3.0
240	2.5
260	2.5
280	2.5
300	2.0

Kind of Surface.	Rise per Ft. of Width.
Vitrified Block.	[illegible] "
Wood Block.	[illegible] "
Bituminous Surface	[illegible] "
Concrete Surface.	[illegible] "
Stone Block.	½" to ¾"
Waterbound Macadam	½" to ¾"

Note:
In Widening and Superelevation Curves, carry the Regular Grade through on the Center Line of the Roadway, and make all Widening on Inside of Curves

Note:
All Proportions for Concrete as shown on Cross-Sections are Subject to such Variations as are Stated in the Specifications.

FIG. 59.—(*Continued*)
State of Pennsylvania.

Standard Sections of Highways of New Jersey State Highway Department

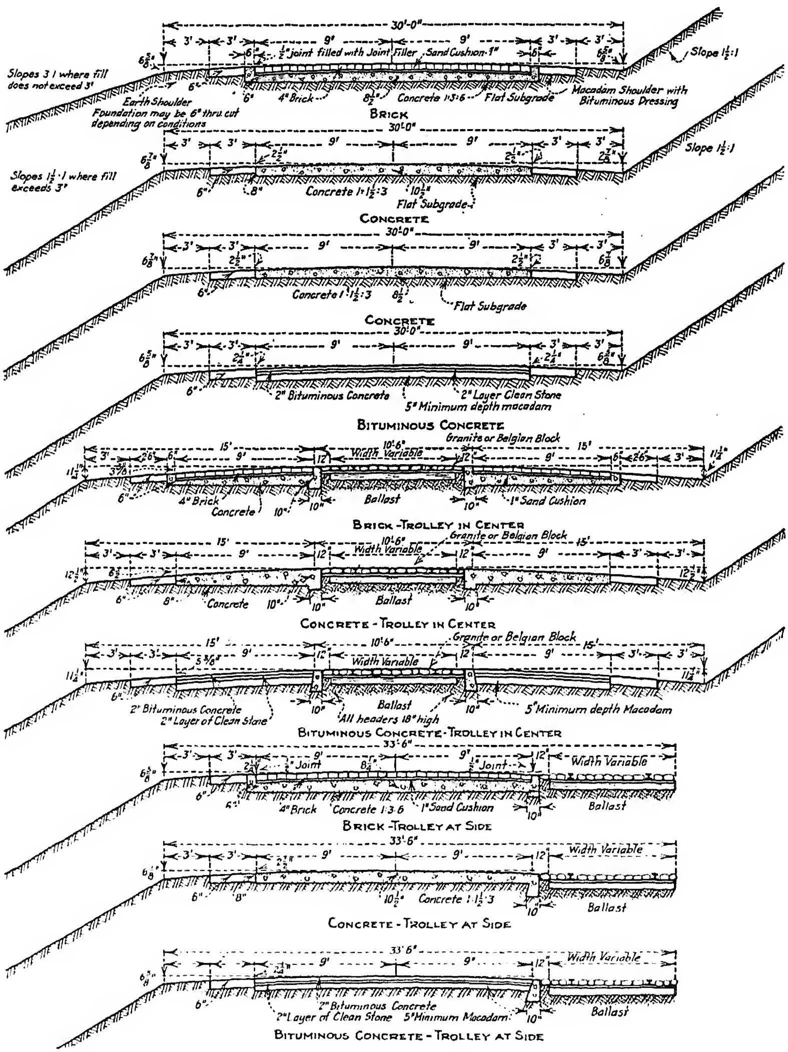


FIG. 60.—Typical Sections (New Jersey).

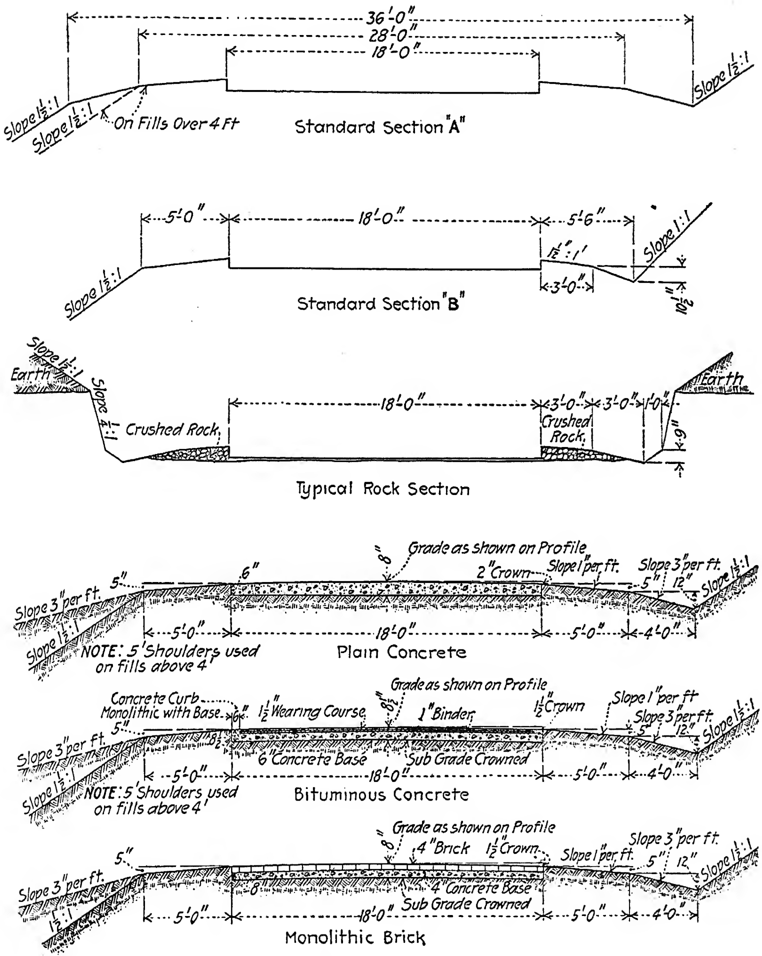


FIG. 61.—Typical sections (Indiana).

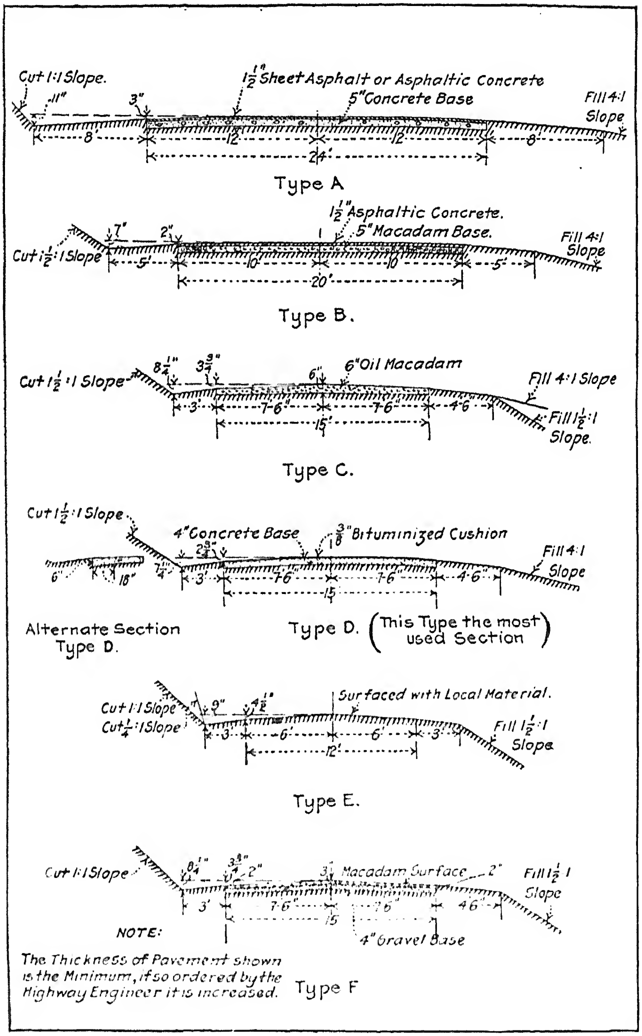


FIG. 62.—Typical Sections (California).

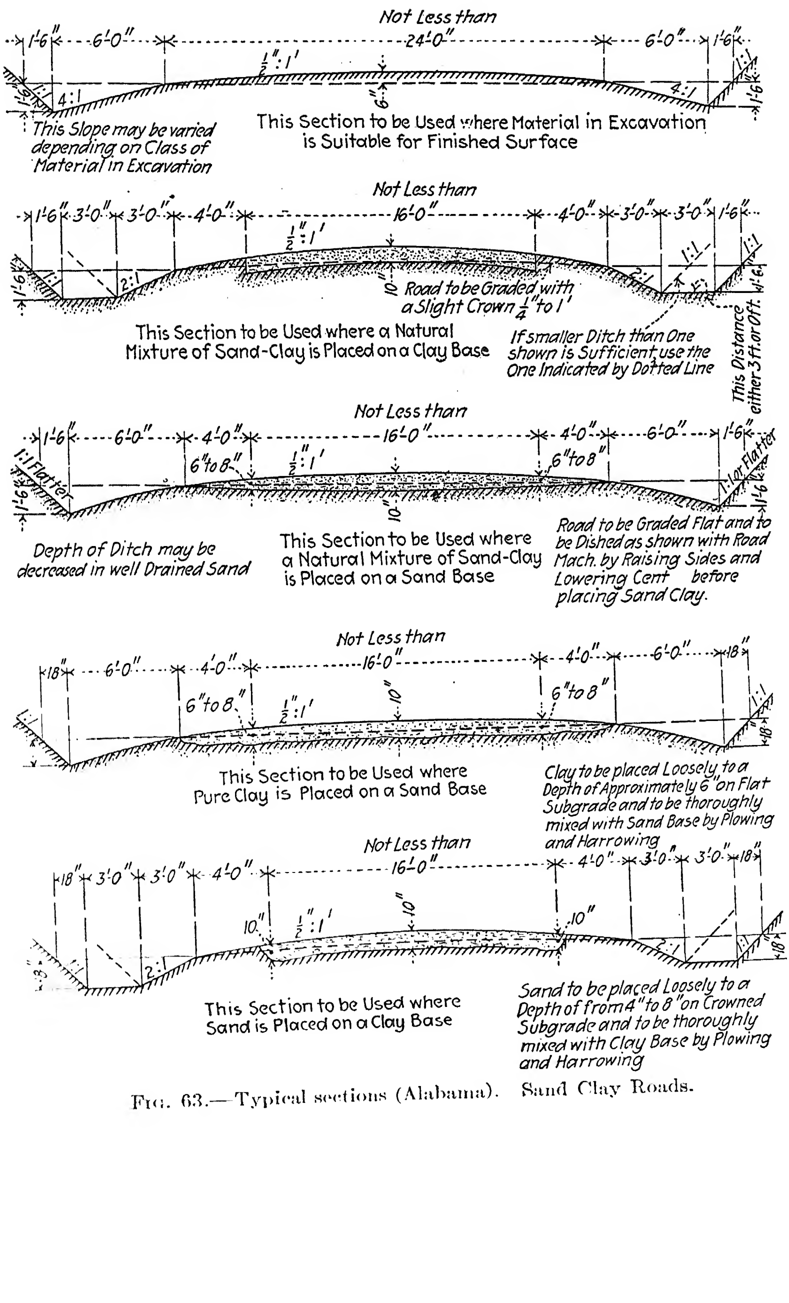


Fig. 63.—Typical sections (Alabama). Sand Clay Roads.

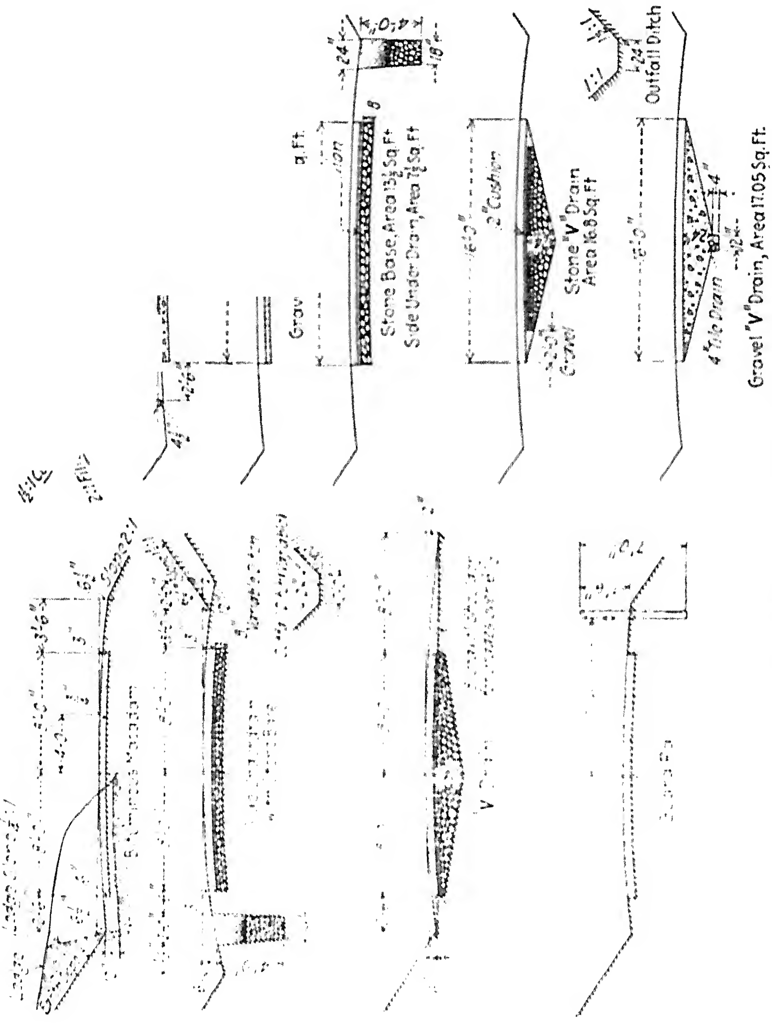


Fig. 64.—Typical sections (Maine).

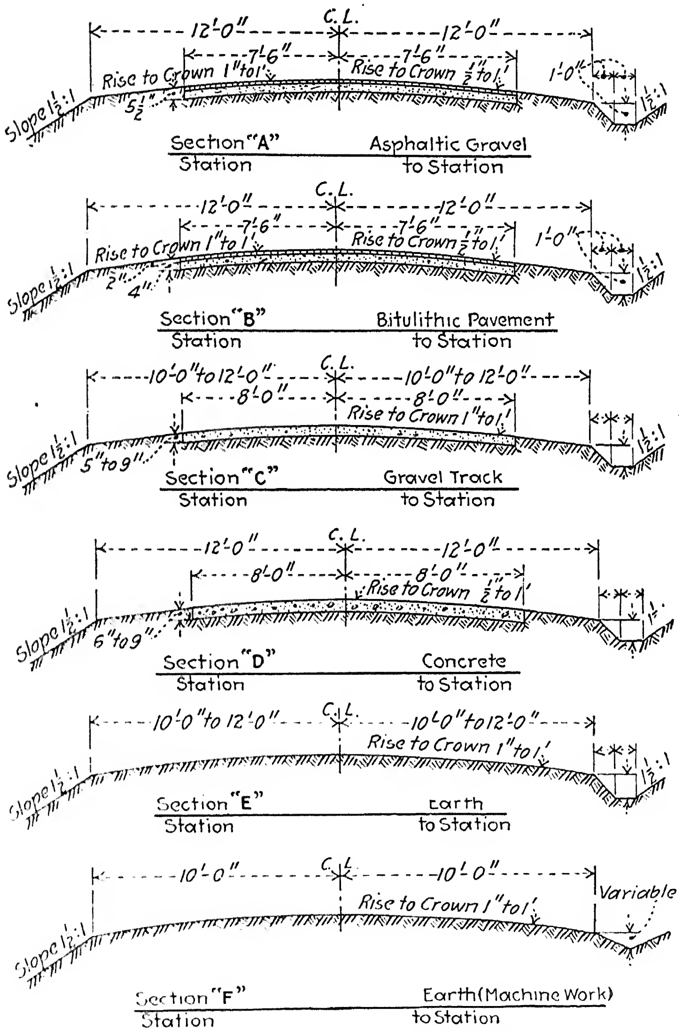


FIG. 65.—Typical sections (Wyoming).

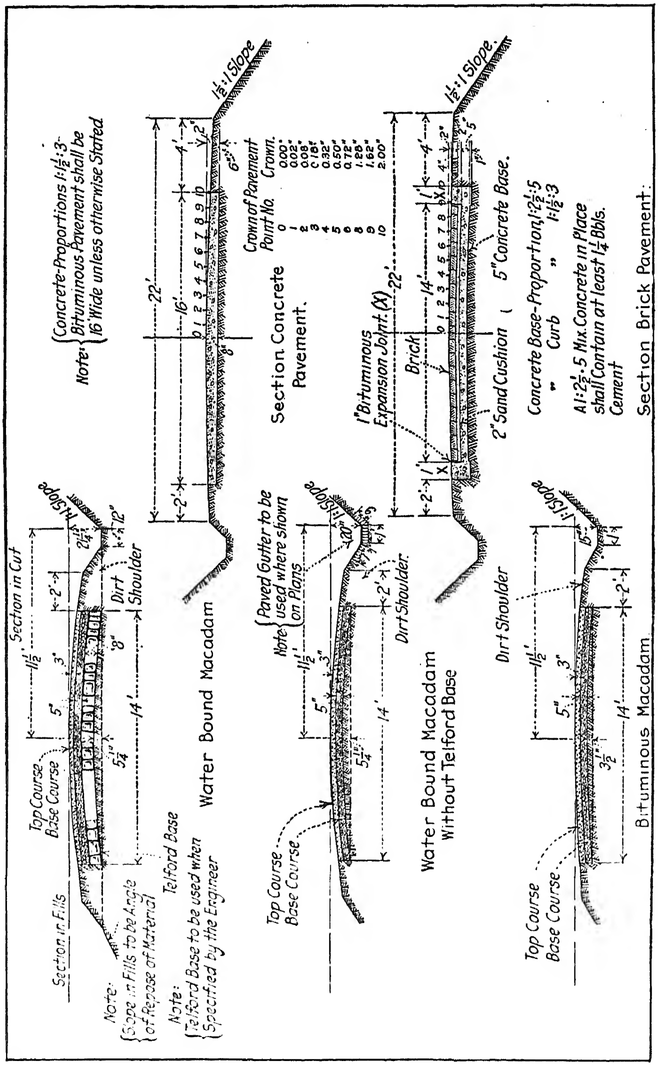


FIG. 66.—Typical Sections (West Virginia).

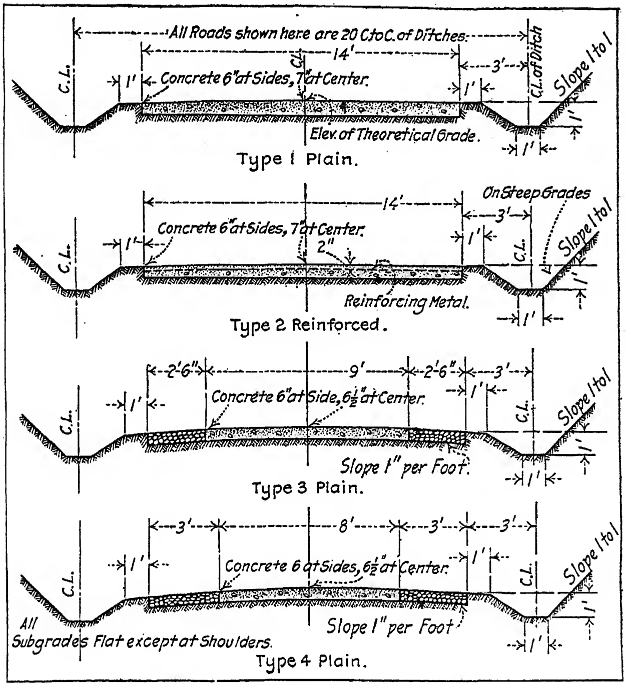


FIG. 66.—(*Continued*).

Recommended Practice in Typical Sections High Type Roads.—The following figures illustrate the author's ideas in regard to desirable sections for high class roads under different grading conditions.

Macadam Roads (Figs. 67 and 68)
  Single and double track.
Rigid Pavements (Fig. 69)
  Double track.
Car Track Sections (Figs. 70 and 71)

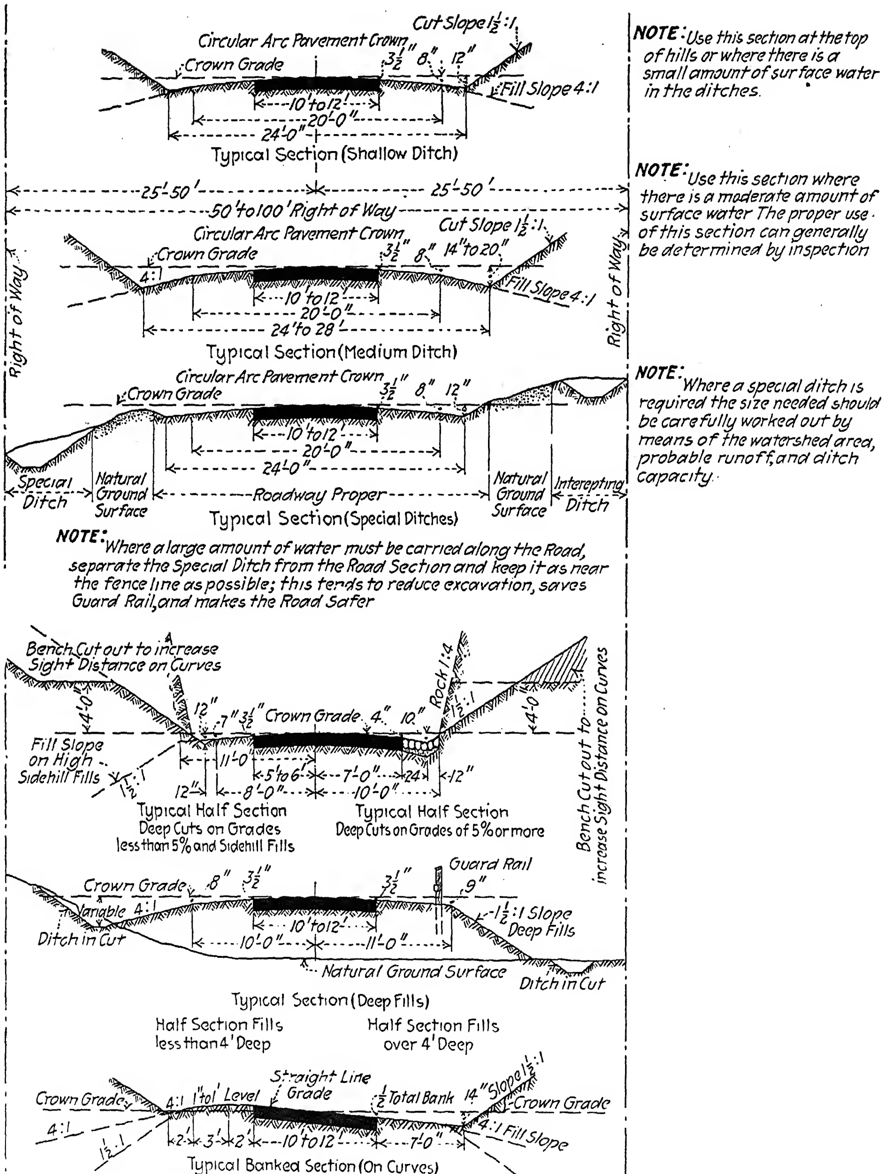


Table of Banked Crowns	
Radius of Road C. L	Rate of Banked Crown
50' to 200'	$1\frac{1}{4}$" to 1'
200' to 500'	1" to 1'
500' to 800'	$\frac{3}{4}$" to 1'
800' to 1000'	$\frac{1}{2}$" to 1'

NOTE: Single Track Macadam Roads do not have enough Traffic to warrant widening the Pavement at Curves

FIG. 67.—Single track macadam or gravel roads. (Suitable for roads carrying up to about 300 vehicles per day.)

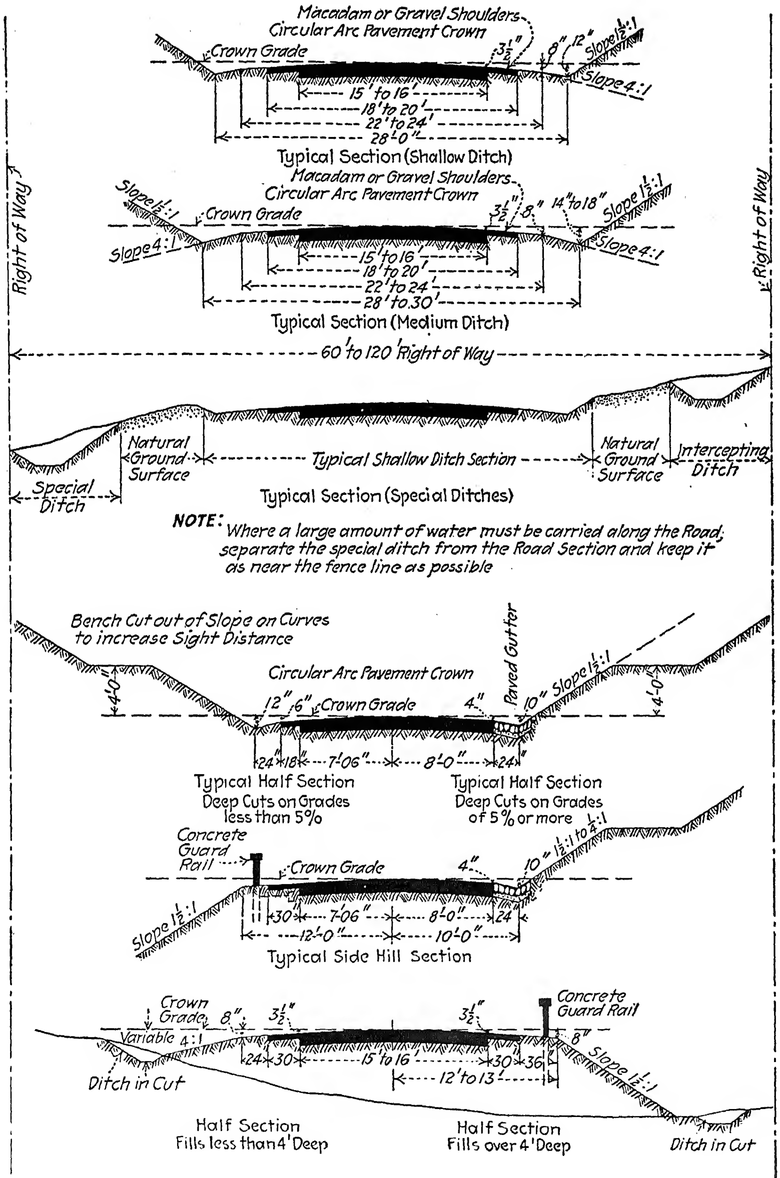
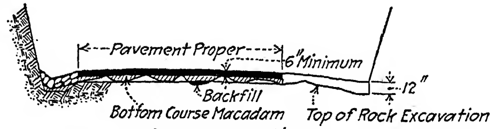


FIG. 68.—Double track macadam roads. (Suitable for local service or secondary state routes carrying from 300 to 1800 vehicles per day in the summer season.)

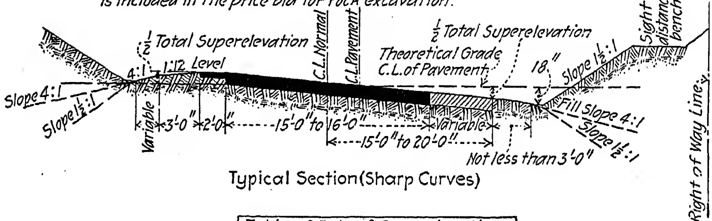


Typical Rock Section

NOTES:

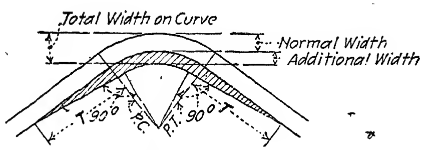
Rock excavation will be paid for to an elevation 12 inches below the surface of the finished road and no rock excavation will be paid for below this elevation or outside of the neat side slopes shown on the plans.

No part of the solid rock shall be closer than 6 inches to the top of the finished section. All depressions under the pavement proper lower than the bottom of the bottom course of the pavement shall be backfilled with stone chips, filled with sand or gravel, and rolled or tamped until firm and hard. This backfill is included in the price bid for rock excavation.



Typical Section (Sharp Curves)

Table of Rate of Superelevation	
Radius of Road Center Line in Feet	Rate of Superelevation
50 - 200	1¼ in. to 1 foot
200 - 500	1 " " 1 "
500 - 800	¾ " " 1 "
800 - 1000	½ " " 1 "



Pavement Widening Layout

Table of Pavement Widening		
Radius of Road Center Line in Feet	Total Width Pavement on Curves	4" Feet
50 Feet	29 Feet	100
75 "	25 "	100
100 "	23 "	100
200 "	21 "	90
300 "	20 "	80
400 "	20 "	80
500 "	19 "	70
600 "	18 "	50

NOTE: *Use normal Pavement Width on Curves having a radius of more than 600 feet*

Table of Recommended Total Depth of Macadam Pavements on Different Soils

Pavement in Cut or Fill	Soils		
	Sand or Gravel	Loam	Heavy Clay or Quicksand
In Cut	8"	9" to 12"	15" to 24"
On Fills less than 1 ft deep	8"	9" to 12"	15" to 24"
" " 1 ft. to 3 ft "	8"	9"	12" to 15"
" " over 3 ft. "	8"	8"	9"

Fig. 68.—(*Continued*).

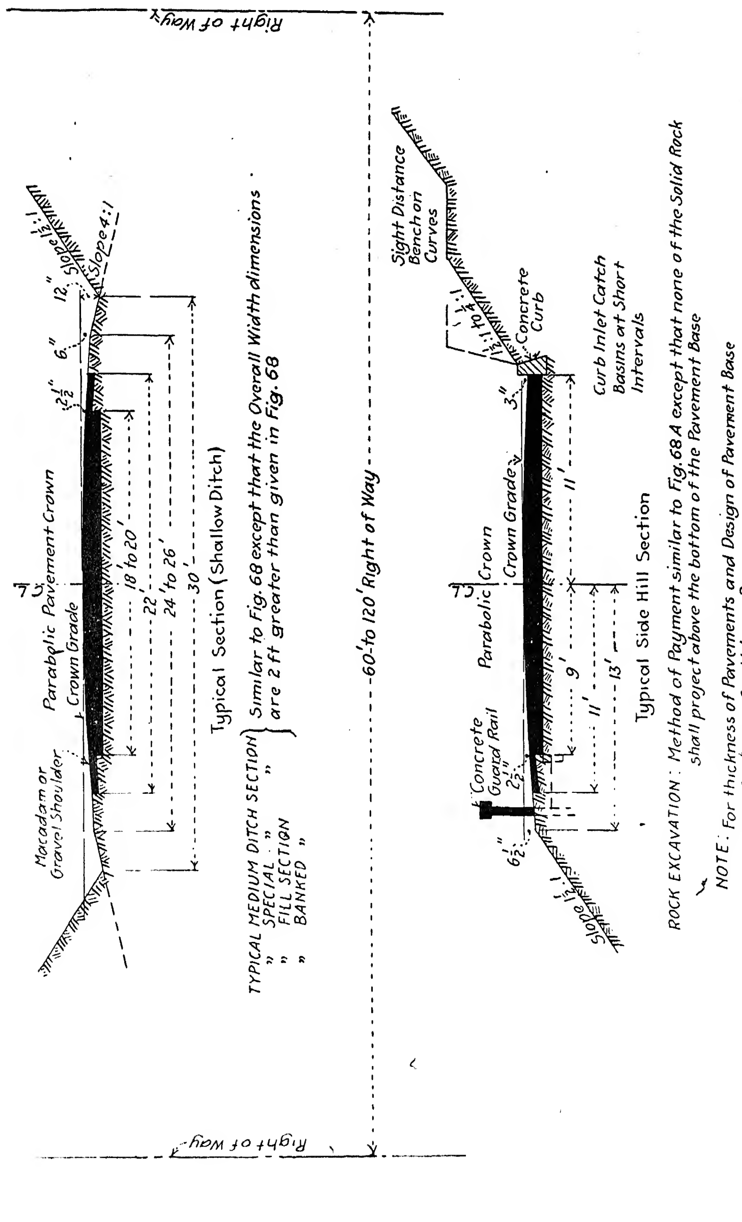


FIG. 69.—Special sections rigid pavement roads. (Roads carrying over 1800 vehicles per day.)

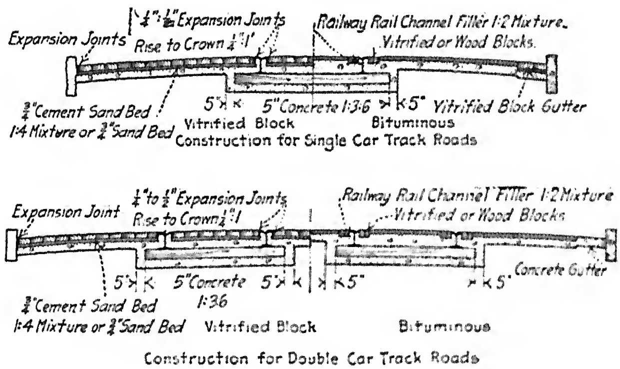


Fig. 70.

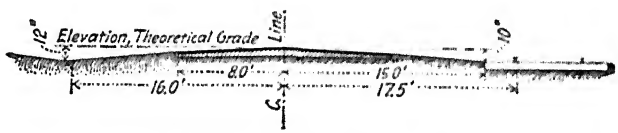


Fig. 71.—Car track sections.

MOUNTAIN ROAD SECTIONS

Discussion.—The desirable requirements for mountain road sections are the same as for the roads previously discussed but on steep sidehill work the width of grading used for ordinary topography would be prohibitive in cost. As most of these roads are natural soil roads the crown is the only element of the section not covered in the previous discussion. For the gravel or stony

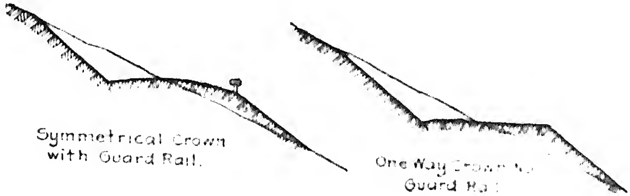


Fig. 72.

material usually encountered ¾ in. to 1 ft. is generally satisfactory. For sand or heavy soils 1 in. to 1 ft. is better practice. The old idea that crown should be increased on steep grades has been abandoned for while that expedient undoubtedly helped the drainage it caused more inconvenience to traffic

than it was worth. In many cases present practice decreases the crown on steep grades to give better vehicle control. Crowns on mountain roads are also affected by the absence of guard rail or other safety provisions. The ordinary symmetrical crown is used where wall or guard rail protects the dangerous outside slope but on many roads so much rail would be needed that it is prohibitive in cost and where it can not be used the road is tipped one way in a continuous slant toward the hill so that if

FIG. 73.—Good example of the "one way crown" section. Note also the careful clearing.

a machine skids it will slide in against the cut slope. This kind of a section is not as comfortable to ride as the ordinary crown but if the surface is at all greasy the element of increased safety outweighs any minor inconvenience of side tilt.

Effect of Width on Cost.—The width of section has more effect on cost than any other part of the design. On a new side hill location the relation of width to cost can be roughly established. It will of course vary for different side slopes of the hill and different cut slopes of the excavation but the relation will be

approximately as follows, for balanced sections (Table 23, page 200).

Assumed 25° Sidehill Slope

1:1 slope in cut. 1½:1 slope in fill

(S- 8)	10 ft. width (ditch to outside of shoulder)....	4,300 cu. yd. per mile
(S-10)	12 ft. width (ditch to outside of shoulder)....	6,100 cu. yd. per mile
(S-14)	16 ft. width (ditch to outside of shoulder)....	10,200 cu. yd. per mile
(S-16)	18 ft. width (ditch to outside of shoulder)....	12,800 cu. yd. per mile
(S-18)	20 ft. width (ditch to outside of shoulder)....	15,400 cu. yd. per mile

We may say that in general a 20 ft. width requires about 3½ times as much excavation as a 10 ft. width. The relative cost of

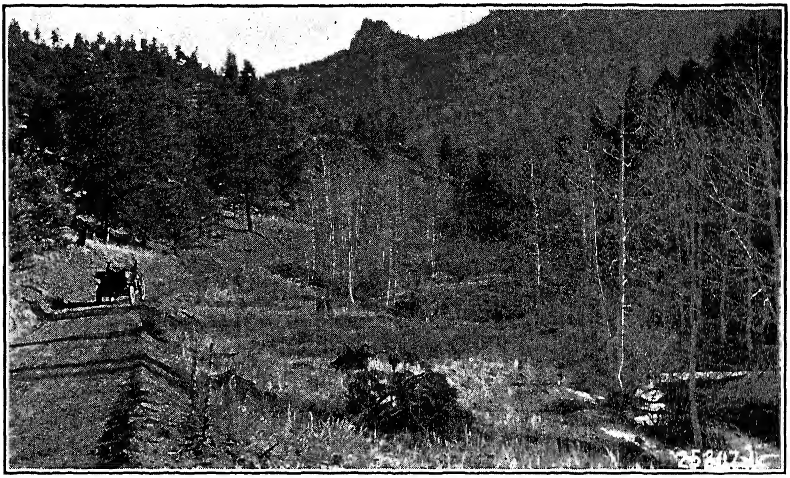


Fig. 74.—"One way crown" section. Note the ridge of earth on the outside of the fill. This is often done to increase safety and reduce side slip. It is in the nature of a wheel guard.

different widths is also affected by the amount of rock excavation which is generally much greater for the wider widths. This depends on the depth of soil overlying the rock. This element affects the cost so much that in certain cases it has been found cheaper to build two separate single track roads for short distances rather than one double track highway.

Mountain roads are classed roughly as double track or single track, meaning the same as for railroad work, a double line of traffic or a single line with turnouts to allow passing. As each foot of extra width is costly it is important to determine the

minimum width of grading that will serve the purpose for these two classifications.

Minimum Width Sidehill Section.—If the roadbed is benched out of solid rock a narrower width will serve as the entire width is firm and stable. If the section is a balanced section part in cut and part in fill it must be wider as embankments on steep

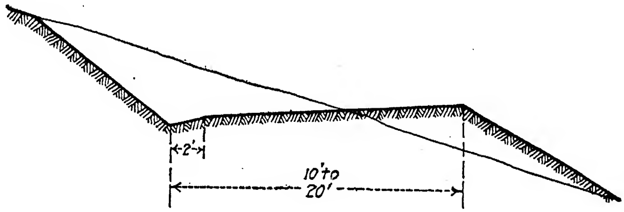


FIG. 75.

slopes are liable to settle, slide or washout and it is not safe to drive as closely to the edge as in the first case. The amount of the road "in solid" is therefore the prime requisite and . . "ft. in solid" is often used as the specification for contract road jobs where engineering design is not used. Present practice favors a minimum single track, total grading width of 10 ft. in rock or where the outer embankment is sustained by a retaining

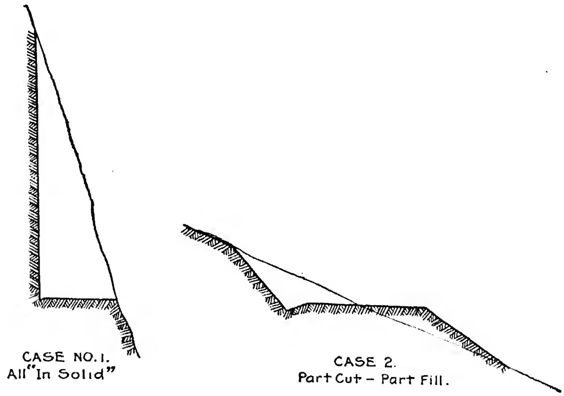


FIG. 76.

wall and a total width of 12 ft. for the ordinary balanced section in earth. Balanced sections are generally used up to 30° side slopes and beyond that toe walls or retaining walls are necessary for earth sections. For a 30° side slope a total grading width of 12 ft. results in approximately 7 to 8 ft. in solid cut. A double track section requires a minimum total grading width of 14 ft. in rock or wall sections and 16 ft. in balanced earth section which

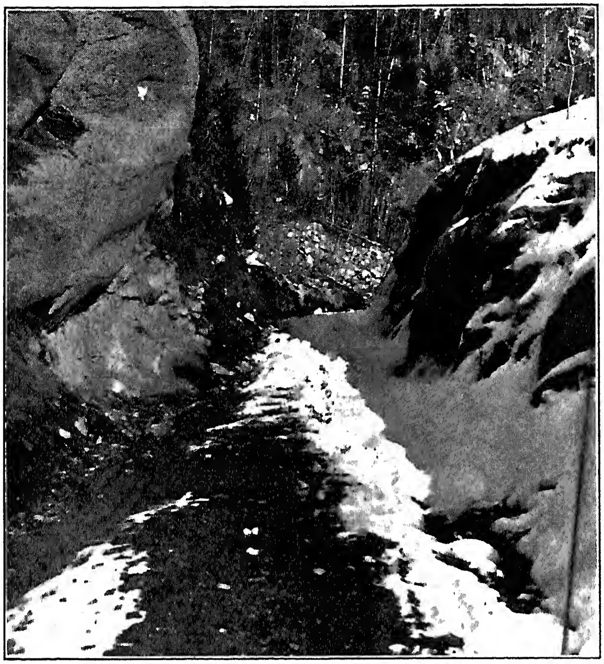


FIG. 77.—Narrow single track through cut section.

FIG. 78.—High turnpiking (gravelled) with deep ditches to raise road on flat above spring floods (Utah).

Superelevation is used on curves in cut but rarely on high through fills. The ditch on the upper side of a superelevated through cut section can be omitted if the cut is short.

Cut and fill slopes depend on the natural material and climate and were discussed on page 160. There is too much tendency to use steep slopes to save on construction cost although excessively flat slopes are not necessary or advised, it being cheaper to take care of minor slides by maintenance. (For effect of cut slopes see Table 23, page 200.)

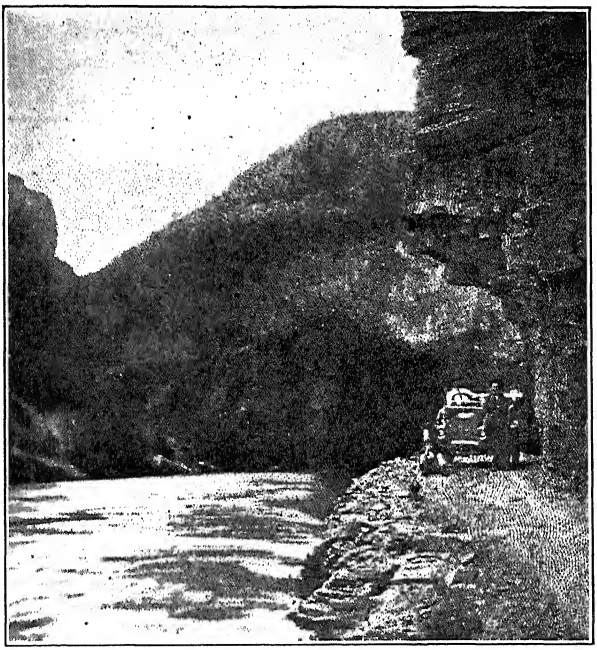


FIG. 87.—Half tunnel section.

Wall Sections.—These sections are used where the natural hill slope is practically as steep or steeper than the stable embankment slope. Toe or retaining walls are necessary for earth embankments where the natural slope exceeds approximately 30° and for rock fills where the natural slope exceeds approximately 40°. Wall details are described in Volume II and III. Surcharged breast walls are to be avoided if possible.

Intercepting Ditches.—Where considerable water runs down the uphill slope intercepting ditches are used to protect the cut

slope and relieve the road ditch of excess water. These ditches discharge to the nearest cross culvert and are an important part of the design.

Bench Sections.—Bench sections are used in rock ledge work. (See Sections S-10, Plate D, and Table 23, page 208.)

PLATE D.—MOUNTAIN PIONEER ROADS.

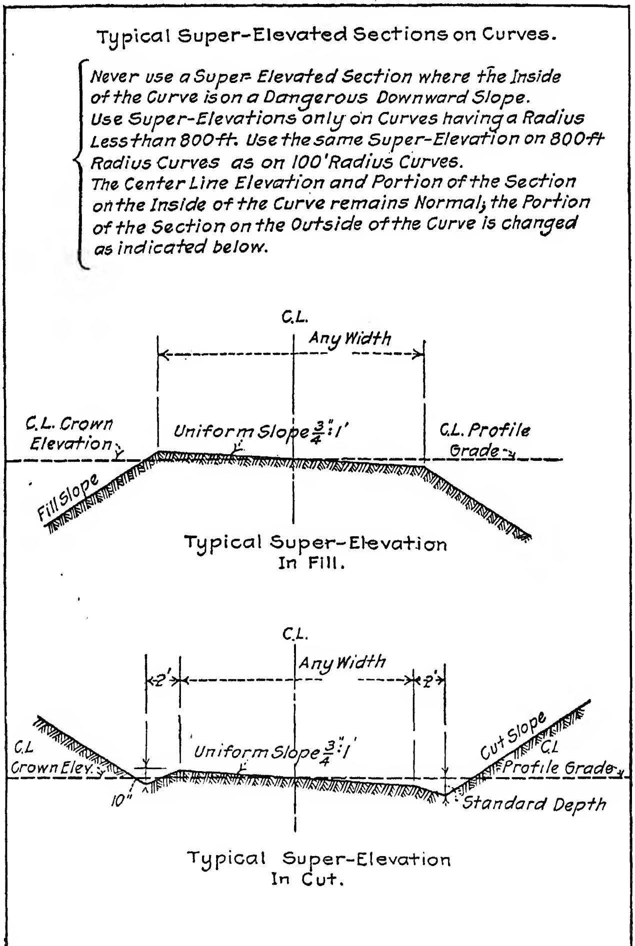


PLATE D.—(*Continued*)

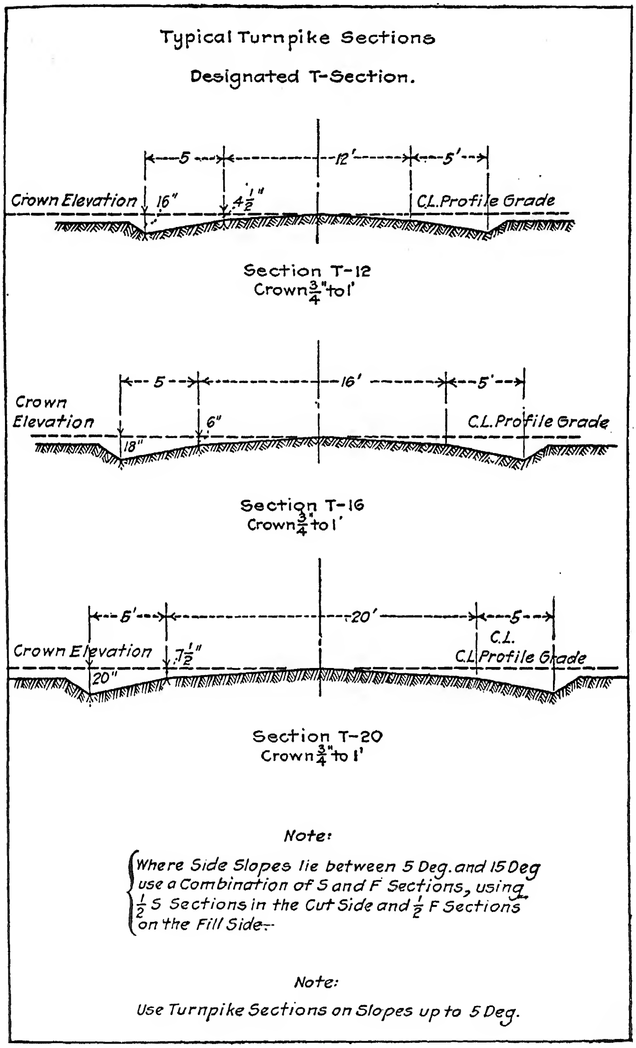


PLATE D.—(*Continued*)

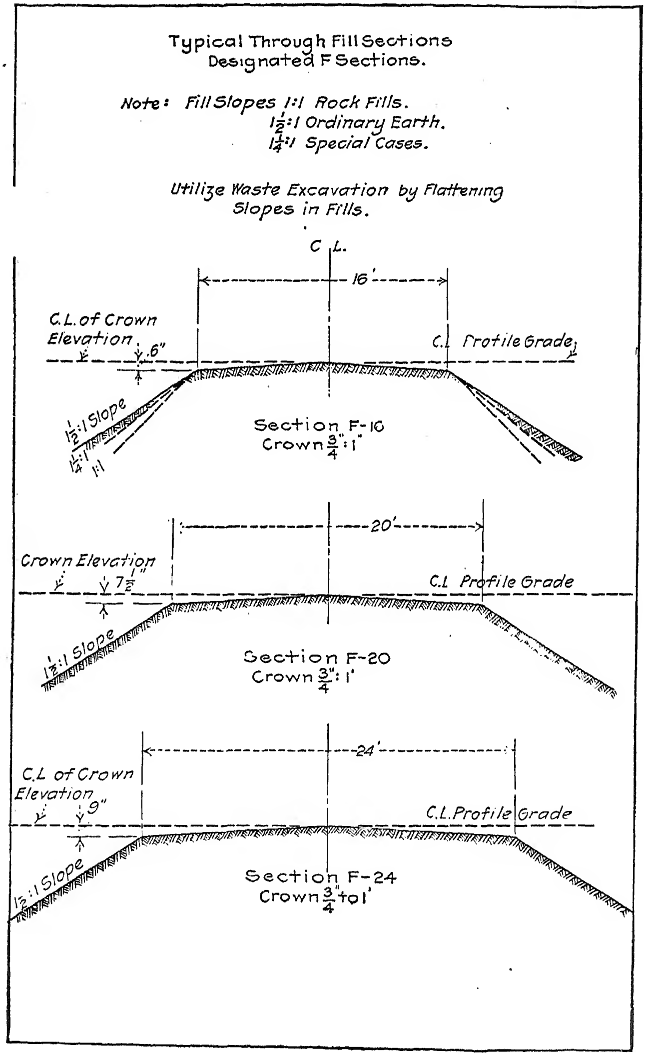


PLATE D.—(*Continued*)

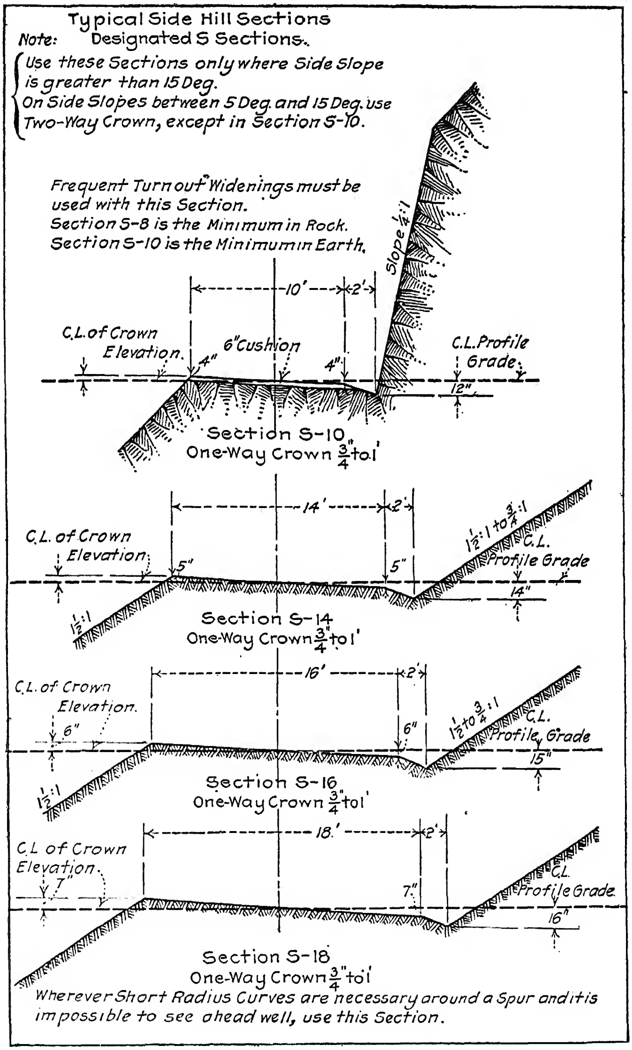


PLATE D.—(*Continued*)

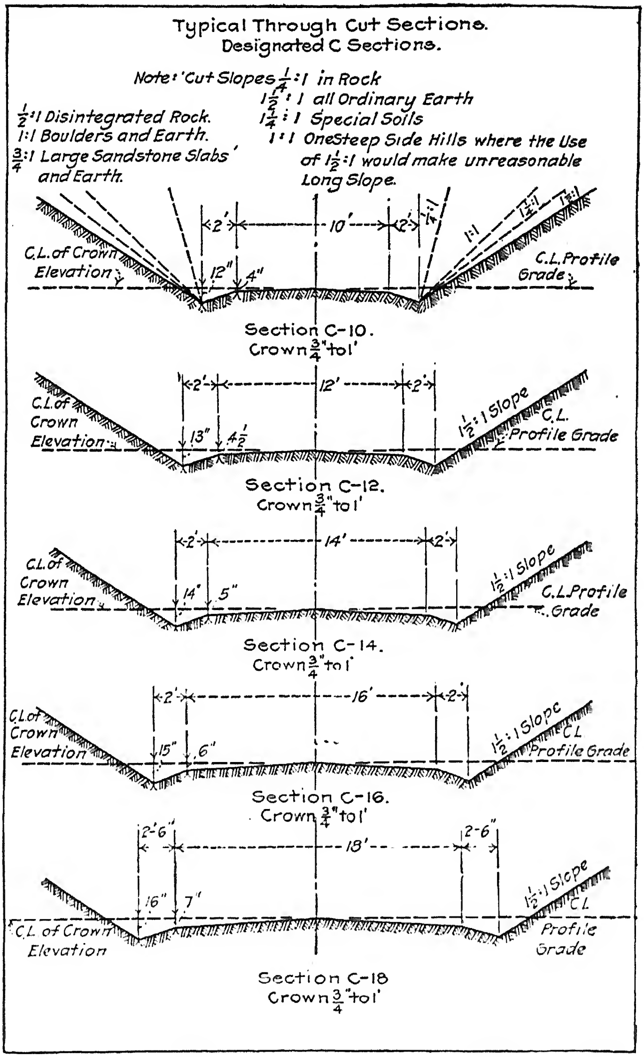


PLATE D.—(*Continued*)

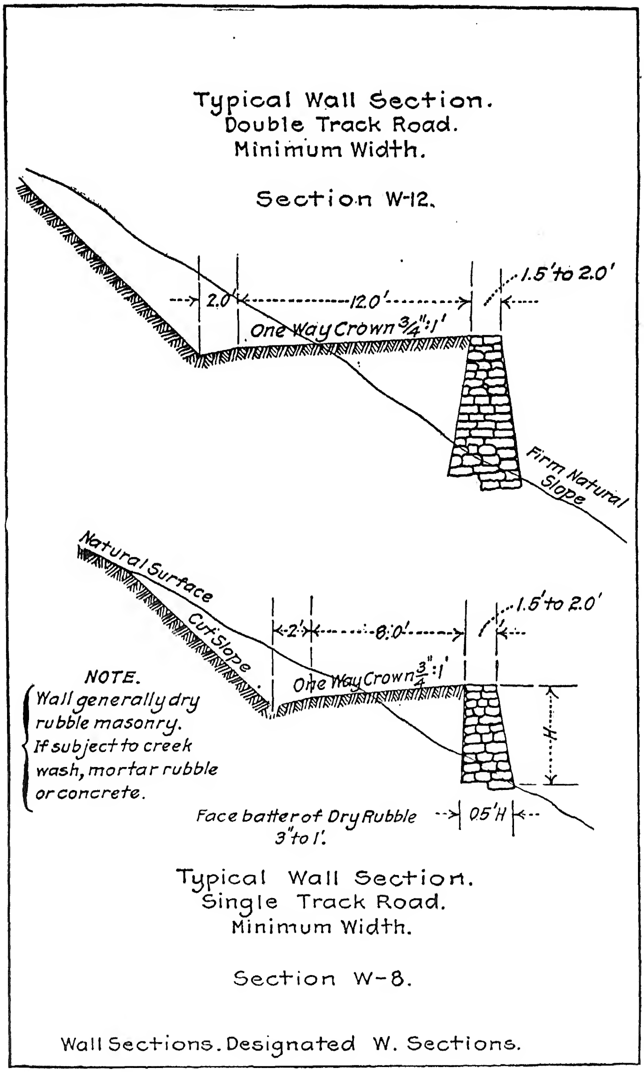
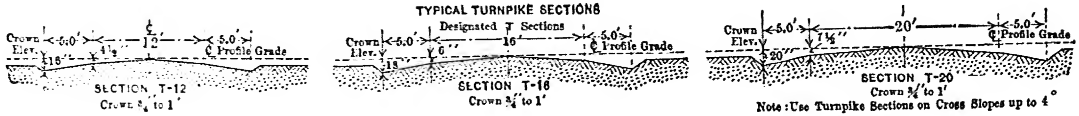


TABLE 23.—BALANCED TURNPIKE SECTIONS USING T-12, T-16 AND T-20

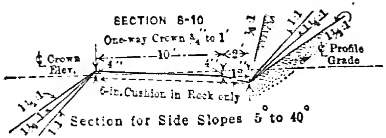


NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile requiring through cuts and fills. These sections are recommended only when the natural cross ground slope is 4° or less.

Natural Ground Surface Cross Slope		Approximate Excavation per 100′ and per Mile for T-12, T-16 and T-20					
		Section T-12		Section T-16		Section T-20	
Degrees	Per Cent.	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile
Level	0%	20 cu. yd.	1050 cu. yd.	24 cu. yd.	1250 cu. yd.	35 cu. yd.	1850 cu. yd.
5°	0%	33 " "	1750 " "	41 " "	2150 " "	59 " "	3100 " "
10°	18%	66 " "	3500 " "	90 " "	4800 " "	115 " "	6100 " "

NOTE.—For light scraper work of this kind 1.3 yd. of excavation are assumed to make 1 cu. yd. of fill. This ratio is used in computing the balanced sections in this table.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-10



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

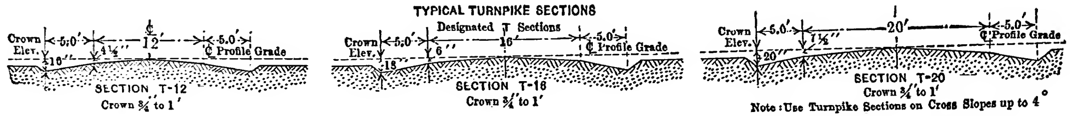
Natural Ground Cross Slope		Approximate Excavation per 100' and per Mile for Different Cut and Fill Slopes																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile
5°	9%	1½:1	1½:1	18	980	1¼:1	1½:1	17	900	1:1	1½:1	16	850	¾:1	1½:1	14	740	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	34	1800	1¼:1	1½:1	31	1650	1:1	1½:1	30	1600	¾:1	1½:1	26	1400	½:1	1¼:1	22	1150	¼:1	1:1	21	1100
15°	27%	1½:1	1½:1	53	2800	1¼:1	1½:1	49	2600	1:1	1½:1	46	2400	¾:1	1½:1	42	2200	½:1	1¼:1	35	1850	¼:1	1:1	27	1450
20°	36%	1½:1	1½:1	90	4800	1¼:1	1½:1	80	4200	1:1	1½:1	70	3700	¾:1	1⅓:1	63	3300	½:1	1¼:1	49	2550	¼:1	1:1	42	2250
25°	47%	....	....	....	....	1¼:1	1½:1	137	7200	1:1	1½:1	115	6100	¾:1	1½:1	97	5100	½:1	1¼:1	70	3700	¼:1	1:1	59	3150
30°	58%	....	....	....	....	....	....	....	....	1:1	1½:1	200	10800	¾:1	1½:1	155	8200	½:1	1¼:1	104	5500	¼:1	1:1	80	4250
35°	70%	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	½:1	1¼:1	155	8200	¼:1	1:1	100	5300
40°	84%	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	¼:1	1:1	155	8200

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

TABLE 23.—BALANCED TURNPIKE SECTIONS USING T-12, T-16 AND T-20

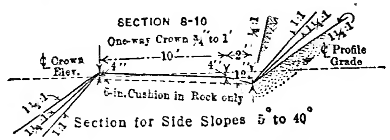


NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile requiring through cuts and fills. These sections are recommended only when the natural cross ground slope is 4° or less.

Natural Ground Surface Cross Slope		Approximate Excavation per 100′ and per mile for T-12, T-16 and T-20					
		Section T-12		Section T-16		Section T-20	
Degrees	Per Cent.	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile
Level	0%	20 cu. yd.	1050 cu. yd.	24 cu. yd.	1250 cu. yd.	35 cu. yd.	1850 cu. yd.
5°	9%	33 " "	1750 " "	41 " "	2150 " "	59 " "	3100 " "
10°	18%	66 " "	3500 " "	90 " "	4800 " "	115 " "	6100 " "

NOTE.—For light scraper work of this kind 1.3 yd. of excavation are assumed to make 1 cu. yd. of fill. This ratio is used in computing the balanced sections in this table.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-10



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

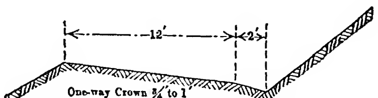
Natural Ground Cross Slope		Approximate Excavation per 100' and per Mile for Different Cut and Fill Slopes																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile
5°	9%	1½:1	1½:1	18	980	1¼:1	1½:1	17	900	1:1	1½:1	16	850	¾:1	1½:1	14	740	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	34	1800	1¼:1	1½:1	31	1650	1:1	1½:1	30	1600	¾:1	1½:1	26	1400	½:1	1¼:1	22	1150	¼:1	1:1	21	1100
15°	27%	1½:1	1½:1	53	2800	1¼:1	1½:1	49	2600	1:1	1½:1	46	2400	¾:1	1½:1	42	2200	½:1	1¼:1	35	1850	¼:1	1:1	27	1450
20°	36%	1½:1	1½:1	90	4800	1¼:1	1½:1	80	4200	1:1	1½:1	70	3700	¾:1	1½:1	63	3300	½:1	1¼:1	49	2550	¼:1	1:1	42	2250
25°	47%	....	....	...	.....	1¼:1	1½:1	137	7200	1:1	1½:1	115	6100	¾:1	1½:1	97	5100	½:1	1¼:1	70	3700	¼:1	1:1	59	3150
30°	58%	....	....	...	.....	....	....	...	.....	1:1	1½:1	200	10800	¾:1	1½:1	155	8200	½:1	1¼:1	104	5500	¼:1	1:1	80	4250
35°	70%	....	....	...	.....	....	....	...	.....	...	....	...	.....	....	....	...	.....	½:1	1¼:1	155	8200	¼:1	1:1	100	5300
40°	84%	....	....	...	.....	....	....	...	.....	...	....	...	.....	....	....	...	.....	....	....	...	.....	¼:1	1:1	155	8200

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-12 (Single Track)



Section for Side Slopes of 5° to 40°

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100' and per mile for Different Cut and Fill Slopes (S-12)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per M
5°	9%	1½:1	1½:1	20	1100	1¼:1	1½:1	18	980	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	41	2200	1¼:1	1½:1	40	2100	1:1	1½:1	38	2000	¾:1	1½:1	35	1850	½:1	1¼:1	27	1450	¼:1	1:1	25	1350
15°	27%	1½:1	1½:1	68	3600	1¼:1	1½:1	66	3500	1:1	1½:1	63	3300	¾:1	1½:1	60	3100	½:1	1¼:1	46	2450	¼:1	1:1	41	2200
20°	36%	1½:1	1½:1	120	6300	1¼:1	1½:1	105	5500	1:1	1½:1	94	5000	¾:1	1½:1	85	4500	½:1	1¼:1	65	3400	¼:1	1:1	[illegible]	3200
25°	47%	....	....	...	....	1¼:1	1½:1	180	9500	1:1	1½:1	145	7700	¾:1	1½:1	130	6900	½:1	1¼:1	94	5000	¼:1	1:1	[illegible]8	4100
30°	58%	....	....	...	....	....	....	...	....	1:1	1½:1	270	14200	¾:1	1½:1	210	11100	½:1	1¼:1	145	7700	¼:1	1:1	110	5800
35°	70%	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	½:1	1¼:1	220	11600	¼:1	1:1	140	7400
40°	84%	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	¼:1	1:1	215	11400

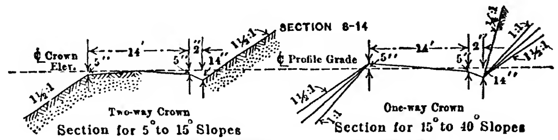
NOTE.—The apparent discrepancy in relative quantities of Sections S-12 and S-14 for side slopes of 5°, and 15° is due to the use of the one way crown for these slopes on single track roads and the two way crown for double track roads.

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-14 (Double Track)



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about the right value for moderately rough country.

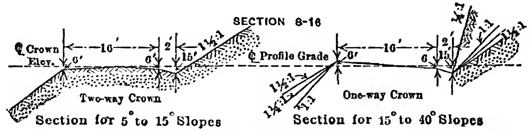
Natural Ground Cross Slope		Approximate Excavation per 100' and per Mile for Different Cut and Fill Slopes (S-14)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	20	1100	1¼:1	1½:1	18	950	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	41	2200	1¼:1	1½:1	38	2000	1:1	1½:1	35	1900	¾:1	1½:1	33	1700	½:1	1¼:1	24	1300	¼:1	1:1	22	1200
15°	27%	1½:1	1½:1	75	4000	1¼:1	1½:1	68	3600	1:1	1½:1	63	3300	¾:1	1½:1	55	2900	½:1	1¼:1	45	2400	¼:1	1:1	40	2200
20°	36%	1½:1	1½:1	150	7900	1¼:1	1½:1	132	7000	1:1	1½:1	115	6100	¾:1	1½:1	105	5600	½:1	1¼:1	85	4500	¼:1	1:1	78	4100
25°	47%	.....	.....	...	.....	1¼:1	1½:1	220	11700	1:1	1½:1	190	10200	¾:1	1½:1	163	8600	½:1	1¼:1	118	6200	¼:1	1:1	96	5100
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	370	19600	¾:1	1½:1	300	15800	½:1	1¼:1	185	9800	¼:1	1:1	137	7200
35°	70%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	½:1	1¼:1	275	14600	¼:1	1:1	180	9500
40°	84%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	¼:1	1:1	270	14300

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill.

Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-16



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

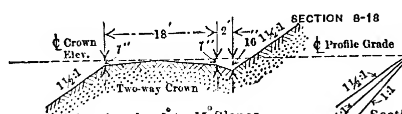
Natural Ground Cross Slope		Approximate Excavation per 100′ and per mile for Different Cut and Fill Slopes (S-16)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	27	1430	1¼:1	1½:1	26	1380	1:1	1½:1	25	1330	¾:1	1½:1	24	1270	½:1	1¼:1	19	1000	¼:1	1:1	18	950
10°	18%	1½:1	1½:1	54	2850	1¼:1	1½:1	51	2700	1:1	1½:1	47	2500	¾:1	1½:1	44	2300	½:1	1¼:1	32	1700	¼:1	1:1	30	1600
15°	27%	1½:1	1½:1	95	5000	1¼:1	1½:1	89	4700	1:1	1½:1	82	4300	¾:1	1½:1	75	4000	½:1	1¼:1	62	3300	¼:1	1:1	56	3000
20°	36%	1½:1	1½:1	195	10300	1¼:1	1½:1	170	9000	1:1	1½:1	150	7900	¾:1	1½:1	137	7200	½:1	1¼:1	106	5600	¼:1	1:1	92	4850
25°	47%	....	....	...	....	1¼:1	1½:1	292	15400	1:1	1½:1	241	12800	¾:1	1½:1	200	10600	½:1	1¼:1	150	7800	¼:1	1:1	125	6600
30°	58%	....	....	...	....	....	....	...	....	1:1	1½:1	466	24600	¾:1	1½:1	368	19500	½:1	1¼:1	230	12100	¼:1	1:1	166	8800
35°	70%	....	....	...	....	....	....	...	....	...	....	...	....	....	....	...	....	½:1	1¼:1	365	19300	¼:1	1:1	227	12000
40°	84%	....	....	...	....	....	....	...	....	...	....	...	....	....	....	...	....	....	....	...	....	¼:1	1:1	350	18500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

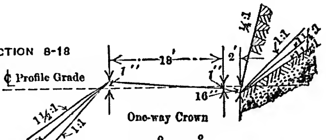
These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill.

Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

TABLE 23.—APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-16



Section for 5° to 15° Slopes



Section for 15° to 40° Slopes

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100' and per Mile for Different Cut and Fill Slopes (S-18)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100'	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	33	1750	1¼:1	1½:1	33	1750	1:1	1½:1	32	1700	¾:1	1½:1	32	1700	½:1	1¼:1	27	1430	¼:1	1:1	26	1380
10°	18%	1½:1	1½:1	67	3500	1¼:1	1½:1	64	3400	1:1	1½:1	60	3200	¾:1	1½:1	56	2950	½:1	1¼:1	41	2200	¼:1	1:1	38	2000
15°	27%	1½:1	1½:1	115	6200	1¼:1	1½:1	110	5800	1:1	1½:1	102	5400	¾:1	1½:1	94	5000	½:1	1¼:1	80	4200	¼:1	1:1	72	3800
20°	36%	1½:1	1½:1	240	12700	1¼:1	1½:1	210	11100	1:1	1½:1	185	9800	¾:1	1½:1	170	9000	½:1	1¼:1	128	6800	¼:1	1:1	107	5700
25°	47%	.....	.....	...	.....	1¼:1	1½:1	365	19400	1:1	1½:1	292	15400	¾:1	1½:1	242	12800	½:1	1¼:1	185	9800	¼:1	1:1	150	7800
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	563	29800	¾:1	1½:1	435	22900	½:1	1¼:1	278	14700	¼:1	1:1	195	10300
35°	70%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	½:1	1¼:1	455	24100	¼:1	1:1	274	14500
40°	84%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	¼:1	1:1	425	22500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill. Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

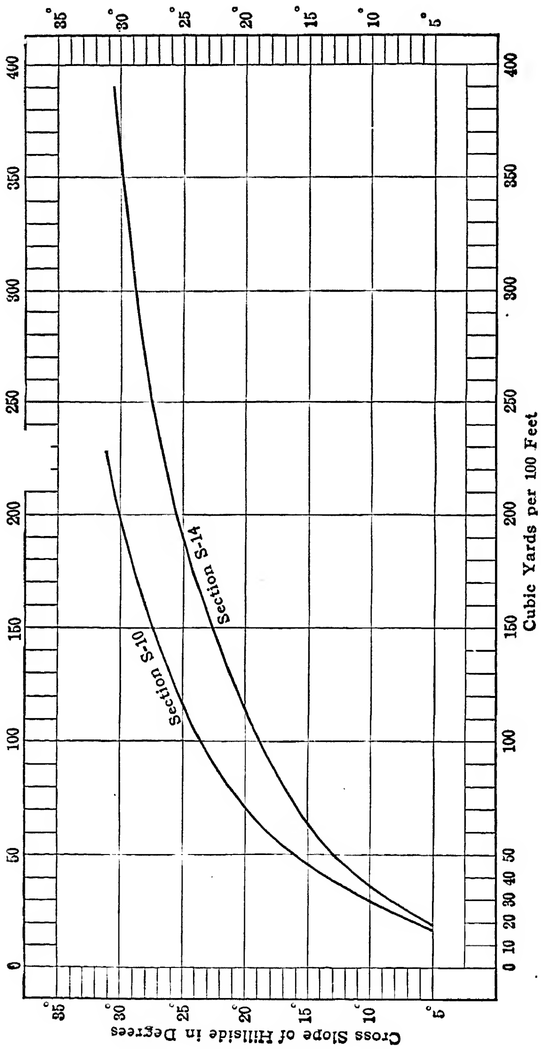
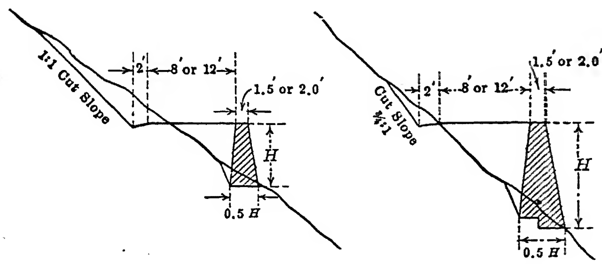


Diagram showing Excavation for Sections S-10 and S-14

Cut Slope 1:1

Fill " 1½:1

TABLE 23.—APPROXIMATE QUANTITIES WALL SECTION MINIMUM
SINGLE TRACK ROAD SECTION W-8
DOUBLE " " " W-12



TYPICAL SECTIONS
30° & 35° Slopes
Ditch Excavation Makes
Fill Back of Wall

TYPICAL SECTIONS
40 & 45 Cross Slopes
Borrow Fill Required

NOTE.—Rough rubble masonry walls to have outside face batter of 3" to 1' and a bottom width of ½ the height. The foundation to be carried to a firm strata.

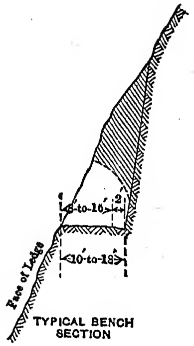
Natural Ground Cross Slope	Approximate Quantities per 100' of Road for W-8 Section				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	46 cu. yd.	55 cu. yd.	None	15 cu. yd.	70 cu. yd.
35°	55 " "	80 " "	None	20 " "	100 " "
40°	100 " "	30 " "	90 cu. yd.	35 " "	155 " "
45°	135 " "	45 " "	100 " "	45 " "	200 " "

TABLE FOR MINIMUM DOUBLE TRACK SECTION W-12

Natural Ground Cross Slope	Approximate Quantities per 100'				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	65 cu. yd.	100 cu. yd.	None	15 cu. yd.	115 cu. yd.
35°	90 " "	140 " "	None	20 " "	160 " "
40°	180 " "	30 " "	200 cu. yd.	45 " "	275 " "
45°	250 " "	45 " "	250 " "	80 " "	375 " "

NOTE.—Above 45° ground slope use Rock Bench Sections, except in unusual cases.
* Retaining wall section on 30° cross slope is not usually economical.

Table 23.—Table of Approximate Quantities Road Benched out of Rock



Using S-8, S-10, S-12, S-14, S-16

Natural Slope of Face of Rock Ledge	Cut Slope	Approximate Excavation in Cu. Yd. per 100′ for Different Sections				
		*S-8	S-10	**S-12	S-14	S-16
50°	¼ : 1	350 cu yd	500 cu yd	660 cu yd	870 cu yd	1,100 cu yd
60°	¼ : 1	600 " "	850 " "	1,200 " "	1,550 " "	2,000 " "
70°	Vertical	560 " "	800 " "	1,050 " "	1,400 " "	1,800 " "
80°	Half Tunnel	460 " "	550 " "	680 " "		

* Minimum width single track in rock.
** Minimum width double track in rock.

Summary of Sections.—The Standard Sections in current use are generally well designed but their use in actual design is too uniform and mechanical. That is, considerable needless grading often results from the failure to vary the section shape to conform to short special local conditions. This point is taken up in detail in the third book of this series and results in noticeable construction savings.

Ditches are also often needlessly deep and dangerous and fail to regulate ground water which is the only excuse given for their use. The use of road ditches for farm drainage is poor policy. Any system of special farm drainage should be separated from the road design except in the matter of culvert elevation.

Right of Way and Clearing Widths.—The width of Right of Way is determined by required grading widths, by required clearing widths, by possible future widening of the grading and by a minimum sight distance where buildings may be erected directly on the road boundary or where a heavy stand of brush or trees grow on the land back of the road boundary. While it

is desirable to provide sufficient width for all the requirements of the future the use of a needless width results in waste land which might better be utilized for farming or building purposes. There have been cases of rights of way 500 ft. wide in flat country which were merely ridiculous.

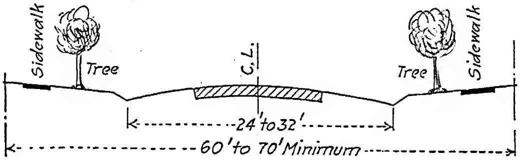


FIG. 88.

The ordinary double track improved road section varies from 24 ft. to 36 ft. ditch to ditch. The cut and fill slopes back of the ditch line rarely take up more than 10 ft. in ordinary topography and experience indicates that a 50 ft. width of right of way will as a rule be satisfactory as far as the grading of the ordinary rural road is concerned. Practically all engineers are agreed

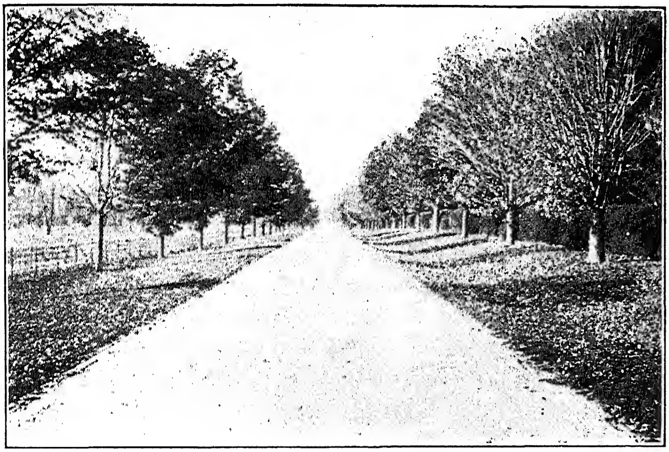


FIG. 89.—Parallel rows of trees, uniformly spaced, make for attractive roadsides. A state highway near Lenox, Mass. Note also shallow ditch and the safety of this entire roadway.

that tree planting and sidepaths for pedestrians are only a matter of time and that an allowance for improvements of this kind are reasonable. Such an allowance would naturally increase the normal right of way width for the usual local service road to approximately 60 ft.

14

On State and National routes where four lines of traffic are anticipated a normal width of 80 ft. ought to serve satisfactorily except as modified for deep cuts and fills, sight distance on sharp curves and clearing widths.

Modifications for deep cuts and high fills show up on the cross sections. Modifications for sight distance can be worked up diagrammatically for each case but in order to give some idea of the approximate increase in right of way widths for sharp curves the following tables are inserted.

TABLE 24.—TABLE OF DISTANCE BETWEEN ℄ OF ROAD AND RIGHT OF WAY LINE ON THE INSIDE OF THE CURVE TO PERMIT CERTAIN SPECIFIED SIGHT DISTANCES ASSUMING THAT THE LINE OF SIGHT IS NOT OBSTRUCTED WITHIN THE LIMITS OF THE RIGHT OF WAY AND THE CURVE IS LONGER THAN THE SIGHT DISTANCE REQUIRED

Road center line radius in ft.	200 ft. Sight distance	300 ft. Sight distance	400 ft. Sight distance	500 ft. Sight distance
	Values given below are the distance from the road center line to the right of way on the inside of the curve to give the sight distance shown at the head of each column.			
100	100.0	.....	.....	.....
150	38.0	150.0	.....	.....
200	26.8	64.3	200.0	.....
250	20.8	50.0	100.0	250.0
300	17.1	40.2	76.3	134.0
400	12.7	29.2	53.6	87.6
500	10.1	23.0	41.8	67.0

TABLE 25.—TABLE OF RADII OF ℄ REQUIRED FOR DIFFERENT SIGHT DISTANCES AND DIFFERENT RIGHT OF WAY WIDTHS ASSUMING THAT THE LINE OF SIGHT IS TANGENT TO THE RIGHT OF WAY

Line.—This permits building being erected on the line. This table indicates minimum curvature for certain limiting right of way widths metropolitan districts.

Total width of right of way in ft. ℄ of road located in center of right of way	200 ft. sight distance	300 ft. sight distance	400 ft. sight distance	500 ft. sight distance
	Values given below are the approximate radii in ft. of the road ℄ to give the required sight distance			
50	212	463	812	1262
60	182	390	682	1056
80	145	301	520	801
100	125	250	425	650

Modifications for clearing depend on the height and thickness of the growth. The object of clearing is first to remove growth within the slope lines, second to provide a clear view and third to clear sufficient width to allow the sun to reach the road, dry it out and melt snow. This last depends a good deal on the direction in which the road is running, the altitude and geographical location. It is entirely a matter of judgment (see Figs. 39, page 139, and 80, page 187) but should be liberal in the forest districts and ranges from 30 ft. in low growth to 150 ft. in adverse locations and high growth. In high altitudes roads are at their best closed in winter and if careful location and liberal clearing will increase the length of the open season it is well worth while as in effect it increases the usefulness of the road by 15 to 25 per cent.

Recommended Practice.—All the evidence seems to indicate that the following normal Right of Way widths will be satisfactory provided they are modified for unusual conditions of grading, sight distance and clearing.

	Main routes, ft.	Secondary roads, ft.	Local roads, ft.
Mountainous regions (cheap land)	150	100	100
Farming country (moderately cheap land)	100	70	50
Metropolitan districts (expensive land)	80	60	50

CHAPTER VI

DRAINAGE

The success of any road depends largely on an effective drainage design. The fundamental idea underlying the various schemes is to prevent ground water from reaching the subgrade and to get the surface water away from the travelled way and out of the longitudinal ditches as soon as possible.

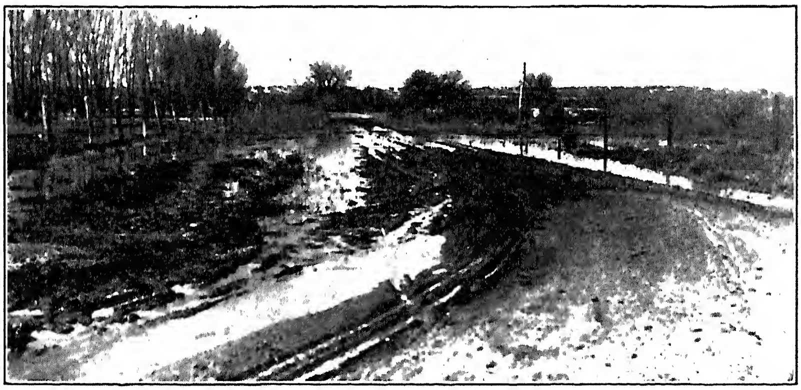


FIG. 90.—Undrained road conditions (Wyoming).

The problem of drainage may be divided into three parts:

1. Cross Drainage.
2. Longitudinal Surface Drainage.
3. Underdrainage.

1. Cross Drainage includes Culverts and Bridges located at natural stream crossings, natural swales, artificial drainage or irrigation ditches, low points on the road profile, equalizing culverts where the road passes through a naturally depressed sump area, overflow culverts in flooded areas and ditch relief culverts on long grades.

Long span bridge design is a specialized subject and no attempt is made to discuss it in a book of this kind which will only consider culverts and small span bridges.

The points to be considered in culvert and bridge design are:

(*a*) Location of structure.
(*b*) Area of waterway.
(*c*) Slope and elevation of inverts.
(*d*) Design strength for dead and live loads.
(*e*) Length of structure.
(*f*) Economical type of structure.

If the funds are limited the cheaper types may be used but all necessary structures must be built not only to protect the road but to establish a reasonable drainage scheme which is recognized

FIG. 91.—Temporary timber box culvert (Utah).

and becomes fixed by usage as the country develops; it is very difficult to change surface drainage in well settled districts without annoying and expensive lawsuits.

Justifiable economy in culvert and bridge design lies very largely in the selection of the most economical type of structure. This is important and well worth while from a money standpoint. The omission of structures, reduction of reasonable waterway, dangerous shortening of length, weakness for reasonable modern loads or high waterways causing ponding are poor economies. For high class macadam or rigid pavement roads, the cost of ordinary culvert work exclusive of long span bridges does not generally exceed on the average over 3 to 8 per cent. of the total

cost of the road indicating that liberality in the essentials of design do not add noticeably to the total cost of a general road system.

(*a*) **Location of Structure.**—Poor location of structures is the most prevalent fault of the usual road drainage scheme. A good location fulfils the fundamental requirement of getting the water across and away from the road as soon as possible. It also considers the desirability of a fairly uniform velocity of flow of the water in the channel and through the structure in order to minimize scour or silting up of the waterway. Sharp changes of direction in the flow of water are undesirable.

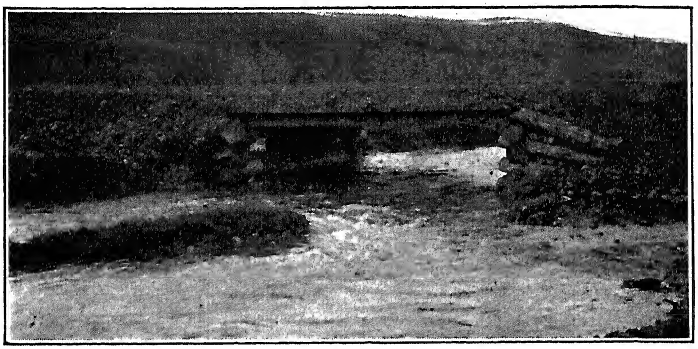


FIG. 92.—Good example of log stringer bridge (State of Utah).

SIMPLE ILLUSTRATIONS OF CULVERT LOCATIONS

Case I.—Simple right angle stream crossing (Fig. 93). There is never any doubt in this case. The structure is placed directly in the stream line and at right angles to the road center line.

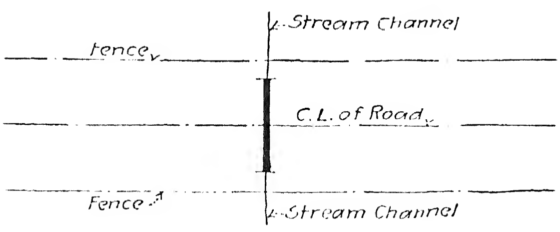


FIG. 93.

Case II.—Stream crossing on skew angle (Fig. 94). In a case of this kind it is desirable to place the culvert in line with the natural stream channel.

The right angle location marked "Poor" saves length of culvert but generally requires four sharp changes in direction of flow which tends to check the velocity of flow and to produce scour and silting up at the angles. Considering maintenance costs it is generally poor economy unless the creek channel can be changed for some distance.

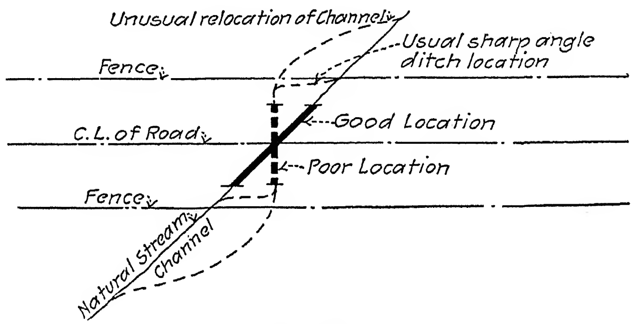


FIG. 94.

Case III.—Where stream must be carried along road for some distance (Fig. 95). The location marked "Good" gets the water on to the low side of the road as soon as possible, minimizes sharp changes in the direction of flow and is desirable unless houses or barns are located on the low side of road between where the stream strikes and leaves the road.

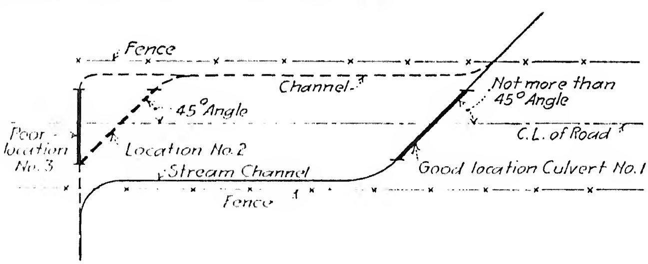


FIG. 95.

Location No. 2 is desirable where houses are located on the low side of the road but not on the high side.

Location No. 3 is not desirable under any conditions as it checks flow and causes trouble by reducing the culvert capacity and encouraging scour and silting. The author has a number of cases in mind where locations of this nature have proved very unsatisfactory.

Case IV.—Ditch relief culverts on side hill location (Fig. 96). Ditch relief culverts on side hill locations are very desirable as they minimize ditch scour. They are placed at any natural gully

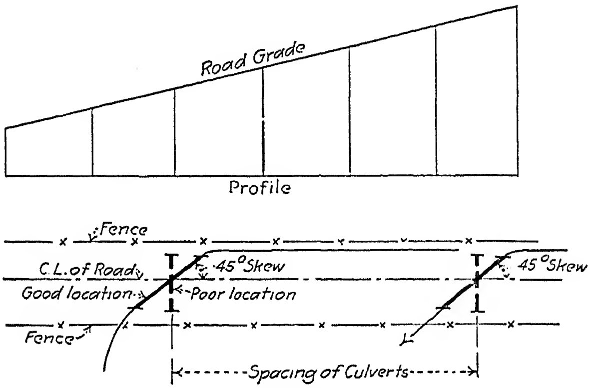


Fig. 96.

formation and on uniform slope formations are spaced from 300 to 500 ft.

The spacing between these ditch relief culverts on sidehill locations depends on the grade, soil, ditch lining and width of

Fig. 97.—Open slat top relief culvert. Note angle with ℄ of road. Pioneer road Colorado.

section. A narrow 10 ft. mountain road requires more relief than a 20 ft. road in the same location as even a small washout will put the narrow road out of commission while a moderately

bad ditch scour will not stop traffic in the second case. No set rules on spacing can be given but current practice favors ditch relief culverts on 8 per cent. grades at intervals not exceeding 300 ft. and on 5 per cent. grades not exceeding 500 ft. If cobble gutter

FIG. 98.—Typical inlet (mountain road) for pipe ditch relief culvert.

or concrete ditch lining is used the distance can be materially increased but is not advised. On long cut and fill hills drop inlets into storm sewers are sometimes necessary to prevent overloading of the ditch.

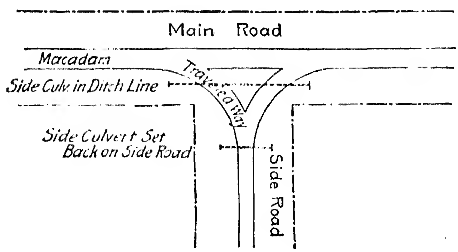


FIG. 99.

Case V. Side Culverts (Fig. 99). In designing culverts under side roads, the length must be great enough to provide an easy turn for traffic; many times a saving in length can be made by placing the culvert a short distance down the side road as shown

in Fig. 99 but this should of course not be done on steep grades.

Don'ts.—*The main fault to avoid in the location design of culverts and bridges is the use of the right angle location where this is not the natural and reasonable layout.* The right angle layout is desirable on account of economy where it fits the conditions.

Do not omit culverts on side hill locations and run the water for long distances in the road ditches.

(*b*) **Area of Waterway.**—The size of opening is usually determined by noting the size of the old structure or, if none exists, the size of other structures over the same stream and by inquiries of neighboring residents or the road commissioner as to how the existing structure has handled the water in the past. As a general rule the size of opening or span should not be reduced below that of the present structure but in the case of steel bridges that have been sold to town boards by enterprising bridge companies it is often found that the span is needlessly long. The evidence of existing structures is the most reliable basis of design but the conclusions should be checked theoretically and for small drainage areas in villages and all drainage areas affecting new locations in sparsely settled districts either the physical evidence of high water or some maximum run off formula must be used. Run off formulæ are based on the rate of rainfall, area of the watershed, topography and soil. The rate of rainfall varies for different geographical locations and the length of the storm. Reliable information for any locality can be obtained from the weather bureau. Short storms develop the greatest intensity and produce the largest runoff for small watersheds. The rates reached by these storms should be considered in designing ditch relief culverts or cross culverts with small drainage areas. A liberal basis for these cases is the 5 or 10 minute duration rate of Table 26, page 220, Table 27, page 221, illustrates the method. Most culvert design is based on a 24 hour precipitation as illustrated in Table 28, page 222, and applies to watersheds of say 0.5 sq. mi. and up. Streams requiring structures of over 10 ft. span generally produce physical evidence of highwater which can be safely used.

Table 30, page 224, gives the size of opening used by the Santa Fé Railroad; Table 31, page 226, gives the size of opening for small culverts used by the New York Central. Table 32,

page 226, gives the size of culvert used by the Iowa Highway Commission. These tables serve to illustrate the application of this principle of design.

Weather bureau records show maximum 24 hour precipitations of 7.66 in. at Portland, Oregon, 5.12 in. at Los Angeles, California, 2.06 in. at El Paso, Texas, 7.03 in. at Kansas City, Missouri, 9.40 in. at New York City and 8.57 in. at Savannah, Georgia. These rates are rarely used for runoff computations as they represent extreme cases of rare occurrence. Good practice uses a 24 hour rate of from 4 to 6 inches. Openings based on these rates where the culvert will handle the water without quite running full will take care of unusual cases by the forced discharge due to the formation of a shallow pond on the up stream side of the road.

Examples of Use of Tables.—Table 29, page 223, gives the normal discharge of small culverts laid at different rates of grade. To illustrate the use of Tables 27 to 32 three examples will be given. Suppose water from 2 sq. mi. of flat farming country in the North Atlantic States is to pass through a culvert having a natural slope of 0.5 ft. to the hundred. Table 28 is figured for a 4 in. rainfall in 24 hours which is reasonable for this section. This table shows a runoff of 334 second ft. for flat farm land. For a slope of 0.5 ft. per 100 table 29 shows that a 5 ft. × 5 ft. culvert will carry the water.

Suppose we have steep rocky ground of say 200 acres or ⅓ sq. mi. in Oklahoma and a culvert slope of 2 ft. per 100. The best data is the Sante Fé Table 30 which gives an opening of 51 sq. ft. at 10 ft. per second or a run off of 510 second ft. Table 29 shows that a 5 × 4 ft. culvert on a 2 per cent. grade will carry this but that the velocity is high and the culvert must have a solid bottom and riprap protection at both ends. Where pipes or solid bottom culverts are used high velocity is not objectionable but where the bridge type is used a sufficiently large opening to keep the velocity down to 10 ft. per second or less is advisable.

Suppose a ditch relief culvert drains 2 acres in the cloudburst region and can be laid on a slope of 3 ft. in a hundred. Use last column Table 27 which gives 12 second ft. which from Table 29 gives a 16 in. pipe.

Practical Considerations Governing the Size of Waterway.—For moderate sized drainage areas the culvert opening is pro-

Table 26.—Rates of Rainfall. Short Storms

Short storms of the greatest intensity occur as cloud-bursts in the mountain and arid regions between the Sierras and the foothills of the Rockies. The intensities of these storms are not well recorded but partial records indicate as high a fall as 11 in. in 1 hour. For these regions culverts for small drainage areas should be made at least twice as large as for eastern or southern conditions. (See last column, Table 27.)

Maximum intensity of Rainfall for different periods taken from the U. S. Weather Bureau Records. Intensity at rate of inches per hour.

Location	5 minute duration, inches per hour	10 minute duration, inches per hour	One hour duration, inches per hour
Atlanta, Ga.	5.5	5.5	1.5
Boston, Mass.	6.7	5.0	1.7
Chicago, Ill.	6.6	5.9	1.6
Cleveland, Ohio	5.6	3.7	1.1
Denver, Colo	3.6	3.3	1.2
Detroit, Mich.	7.2	6.0	2.2
Duluth, Minn.	3.6	2.4	1.4
Galveston, Tex.	6.5	5.6	2.6
Jacksonville, Fla.	7.4	7.1	2.2
Milwaukee, Wis.	7.8	4.2	1.3
Memphis, Tenn.	6.6	4.8	1.9
New Orleans, La.	8.2	4.9	2.2
Norfolk, Va.	5.8	5.5	1.6
Omaha, Neb.	6.0	4.8	1.6
Philadelphia, Penna.	5.4	4.0	1.5
Savanah, Ga.	6.6	6.0	2.2
St. Louis, Mo.	4.8	3.8	2.3
Washington, D. C.	7.5	5.1	1.8

Table 27.—Maximum Runoff. Small Watersheds
Burkle-Ziegler, Sewer Formula

$$\text{Cubic feet per second per acre reaching culvert} = C \times \left\{\begin{array}{l}\text{Av. cu. ft. rainfall}\\ \text{per second per acre}\\ \text{during heaviest fall.}\end{array}\right\} \times \sqrt[4]{\frac{\text{Av. slope of ground in feet per 1000}}{\text{No. of acres drained}}}$$

C = 0.75 for paved streets and built up business blocks.
C = 0.625 for ordinary city streets.
C = 0.30 for villages with lawns and macadam streets.
Assumed C = 0.25 for farming country. Note.—This value is high from the standpoint of sewer design but culverts are short and might better be liberal in size.
One inch of rainfall per hour equals 1 cu. ft. per second per acre.

Discharge in Cubic Feet per Second

Area in acres	Rate of rainfall 4 in. per hour						[1]Assumed Runoff steep stony mountain slopes
	Fall 5 ft. in 1000		Fall 20 ft. in 1000		Fall 50 ft. in 1000		
	C = 0.30	C = 0.25	C = 0.30	C = 0.25	C = 0.30	C = 0.25	Rainfall 8 in. per hour
1	1.8	1.5	2.5	2.1	3.1	2.7	6
2	3.0	2.5	4.2	3.5	5.4	4.5	12
3	4.1	3.4	5.7	4.8	7.2	6.0	18
4	5.0	4.2	7.2	6.0	9.0	7.5	23
5	6.0	5.0	8.5	7.1	10.7	8.9	28
6	6.8	5.7	9.7	8.1	12.2	10.2	33
7	7.7	6.4	10.9	9.1	13.7	11.4	38
8	8.5	7.1	12.0	10.0	15.1	12.6	42
9	9.3	7.8	13.2	11.0	16.5	13.8	46
10	10.1	8.4	14.3	11.9	18.0	15.0	50
20	16.9	14.1	24.0	20.0	30.2	25.2	90
30	23.0	19.2	32.5	27.1	40.7	33.9	120
40	28.5	23.8	40.3	33.6	50.9	42.4	150
50	33.6	28.0	47.7	39.8	60.0	50.0	180
60	38.6	32.2	54.6	45.5	68.7	57.3	200
70	43.3	36.1	61.4	51.2	77.3	64.4	225
80	48.0	40.0	67.9	56.6	85.2	71.0	250
90	52.4	43.7	73.9	61.6	93.1	77.6	275
100	56.7	47.3	80.2	66.8	100.8	84.0	300
200	95.4	79.5	134.6	112.2	169.7	141.4	550
300	129.0	107.7	182.9	152.4	229.7	191.4	750
400	160.0	133.6	227.0	189.2	285.6	238.0	880
500	190.0	158.0	268.0	223.5	336.6	280.5	980
600	216.0	180.0	307.0	256.0	387.0	322.8	1,050
640	230.0	[2]192.0	323.0	269.0	406.3	338.6	1,100

[1] Based on Santa Fe Table 30.
[2] 200 second feet by Table 28.

TABLE 28.—MAXIMUM RUNOFF, DICKENS FORMULA

$D = C\sqrt[4]{M^3}$ Runoff expressed in second feet

The following tabulation is for a 24 hour precipitation of 4 in. rain and for topography similar to the farming sections of the Eastern Atlantic States. For 6 in. in 24 hours correct the quantities in proportion to C as follows:

4-in. rainfall		6-in. rainfall	
Flat country	$C = 200$	Flat country	$C = 300$
Rolling country	$C = 250$	Rolling country	$C = 325$
Hilly country	$C = 300$	Hilly country	$C = 350$

For steep stony watersheds and a 6-in. rainfall use the Oklahoma Column of Table 30.

Area in square miles	Flat country C 200	Rolling country C 250	Hilly country C 300
0.1 = 64 acres	36	45	54
0.2	60	75	90
0.3	81	101	121
0.4	100	125	150
0.5	119	149	180
0.6	136	170	204
0.7	153	191	229
0.8	169	211	253
0.9	185	231	277
1.0	200	250	300
2.0	334	417	501
3.0	456	570	684
4.0	564	705	846
5.0	668	835	1002
6.0	764	955	1146
7.0	860	1075	1290
8.0	950	1188	1426
9.0	1038	1297	1556
10.0	1122	1402	1682
20.0	1890	2362	2834
30.0	2560	3200	3840
40.0	3180	3975	4770
50.0	3760	4700	5640
60.0	4310	5400	6480
70.0	4840	6050	7260
80.0	5360	6700	8040
90.0	5840	7300	8760
100.0	6320	7900	9480

For areas under 0.1 square mile, see Table 27.

TABLE 29.—APPROXIMATE DISCHARGE CAPACITY CAST-IRON PIPE AND SMALL CONCRETE BOX CULVERTS

Velocity in feet per second — Discharge in cu. ft. per second

Slope in feet per 100	12 in. C. I. P.		14 in. C. I. P.		16 in. C. I. P.		18 in. C. I. P.		20 in. C. I. P.		22 in. C. I. P.		24 in. C. I. P.	
	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.
0.5	....	..	....	..	4.5	6	5.0	9	5.4	12	5.8	15	6.2	19
1.0	....	..	....	..	6.8	9	7.0	12	7.7	17	8.2	22	9.2	29
2.0	7.4	6	8.3	9	9.2	13	10.0	18	10.9	24	11.5	30	12.3	39
3.0	9.2	7	10.3	11	11.2	16	12.2	21	13.4	29	14.2	37	14.8	46
4.0	10.6	8	11.8	12	13.1	18	14.2	25	15.3	34	16.5	43	17.2	54
5.0	11.8	9	13.3	14	14.6	20	16.2	28	17.3	38	18.0	48	19.0	60
6.0	13.0	10	14.6	15	16.2	23	17.5	31	19.0	41	20.0	53	21.3	67
Area sq. ft.	0.78		1.07		1.39		1.76		2.17		2.64		3.14	
Value of R	0.25		0.29		0.33		0.37		0.42		0.46		0.50	

Concrete boxes

Slope in feet per 100	2 ft. × 1.5 ft.		2 ft. × 2 ft.		3 ft. × 2 ft.		3 ft. × 3 ft.		4 ft. × 2 ft.		4 ft. × 3 ft.		4 ft. × 4 ft.		5 ft. × 3 ft.		5 ft. × 4 ft.		5 ft. × 5 ft.	
	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.
0.5	7.0	21	7.7	31	8.6	52	9.7	87	9.7	78	10.8	130	11.6	186	11.9	179	13.0	260	13.8	340
1.0	10.0	30	10.4	42	12.5	75	13.7	123	13.7	110	15.0	180	16.7	267	16.9	254	18.5	370	19.0	475
2.0	14.0	42	14.8	59	17.5	105	19.0	171	19.0	152	22.0	264	23.6	378	23.8	357	26.2	523	28.0	700
3.0	17.2	52	18.3	73	21.6	130	23.5	212	23.5	188	26.5	318	29.0	464	29.5	443				
4.0	20.0	60	21.0	84	24.8	149	27.5	248	27.0	216	30.5	366								
5.0	22.6	68	23.5	94	27.5	165	31.0	279	31.0	248										
6.0	24.0	72	26.0	104	30.0	180														
Area sq. ft.	3.0		4.0		6.0		9.0		8.0		12.0		16.0		15.0		20.0		25.0	
Value of R	0.60		0.66		0.86		1.0		1.0		1.2		1.33		1.36		1.54		1.66	

NOTE:—Table 29 is figured from Church's diagrams of Kutters formula using $n = 0.011$; the use of these diagrams for short culverts is approximate only but it is sufficiently close for the purposes for which this table is intended.

TABLE 30.—SANTA FÉ RY. SIZE OF OPENING

Area drained in square miles	Areas of waterways sq. ft.			Area drained in square miles	Areas of waterways sq. ft.			Area drained in square miles	Areas of waterways sq. ft.			Area drained in square miles	Areas of waterways sq. ft.		
	Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois
0.01	2.0	2.0	East of Streator use 60% of column A West of Streator use 80% of column A	0.85	91.0	91.0	East of Streator use 60% of column A West of Streator use 80% of column A	4.2	403	409	East of Streator use 60% of column A West of streator use 80% of column A	20	970	1,062	East of Streator use 60% of column A West of Streator use 80% of column A
0.02	4.0	4.0		0.90	94.0	94.0		4.4	417	423		22	1,015	1,120	
0.03	6.0	6.0		0.95	97.0	97.0		4.6	430	436		24	1,060	1,170	
0.04	7.5	7.5		1.0	100.0	100.0		4.8	443	450		26	1,100	1,220	
0.05	9.0	9.0		1.1	110.0	111.0		5.0	455	464		28	1,140	1,275	
0.06	10.5	10.5		1.2	120.0	121.0		5.5	483	493		30	1,180	1,320	
0.07	12.0	12.0		1.3	130.0	131.0		6.0	509	519		32	1,220	1,370	
0.08	13.5	13.5		1.4	140.0	141.0		6.5	533	545		34	1,255	1,415	
0.09	15.0	15.0		1.5	150.0	151.0		7.0	556	572		36	1,290	1,460	
0.10	16.0	16.0		1.6	160.0	162.0		7.5	579	596		38	1,320	1,505	
0.15	25.0	25.0		1.7	170.0	172.0		8.0	601	622		40	1,350	1,575	
0.20	32.0	32.0		1.8	180.0	182.0		8.5	622	644		45	1,435	1,645	
0.25	38.0	38.0		1.9	190.0	192.0		9.0	641	666		50	1,510	1,745	
0.30	44.0	44.0		2.0	200.0	202.0		9.5	660	689		55	1,580	1,840	
0.35	51.0	51.0		2.2	220.0	223.0		10.0	671	709		60	1,650	1,930	
0.40	56.0	56.0		2.4	240.0	244.0		11.0	710	745		65	1,720	2,020	
0.45	62.0	62.0		2.6	260.0	264.0		12.0	740	781		70	1,780	2,100	
0.50	66.0	66.0		2.8	280.0	284.0		13.0	775	815		75	1,840	2,180	
0.55	70.0	70.0		3.0	300.0	304.0		14.0	805	857		80	1,900	2,255	
0.60	74.0	74.0		3.2	321.0	326.0		15.0	835	893		85	1,980	2,330	
0.65	78.0	78.0		3.4	340.0	345.0		16.0	865	930		90	2,015	2,405	
0.70	81.0	81.0		3.6	357.0	362.0		17.0	890	951		95	2,065	2,475	
0.75	85.0	85.0		3.8	373.0	379.0		18.0	920	998		100	2,120	2,545	
0.80	88.0	88.0		4.0	388.0	394.0		19.0	945	1,020		110	2,220	2,690	

			East of Streator use 60% of column A West of Streator use 80% of column A				East of Streator use 60% of column A West of Streator use 80% of column A				East of Streator use 60% of column A West of Streator use 80% of column A				East of Streator use 60% of column A West of Streator use 80% of column A
120	2.315	2.820		300	3,615	4,690		850	5,940	7,640		2,000	8,820	11,450	
130	2.405	2.955		325	3,770	4,860		900	6,080	7,875		2,200	9,240	11,960	
140	2,500	3.080		350	3,900	5,040		950	6,230	8,170		2,400	9,605	12,490	
150	2,580	3.240		375	4.035	5,220		1,000	6,380	8,410		2,600	9,970	12,995	
160	2.665	3.330		400	4,165	5,400		1,100	6,705	8,720		2,800	10,370	13,680	
170	2.745	3.445		450	4,385	5,660		1,200	6,960	9,030		3,000	10,640	14,370	
180	2.820	3.560		500	4,610	5,920		1,300	7,230	9,340		3,500	11,445	15,050	
190	2.900	3.665		550	4,825	6,175		1,400	7,480	9,650		4,000	12,160	15,740	
200	2.970	3.775		600	5,030	6,440		1,500	7,725	9,960		4,500	12,825	16,475	
220	3.115	3.980		650	5,230	6,695		1,600	7,960	10,270		5,000	13,500	17,275	
240	3.245	4.152		700	5,420	6,835		1,700	8,195	10,580		5,500	14,080	18,125	
260	3.370	4.330		750	5,610	7,170		1,800	8,390	10,890		6,000	14,520	18,975	
280	3.495	4.510		800	5,800	7,400		1,900	8,625	11,200		6,500	15,140	19,825	

NOTE.—The above classification by states is for convenience only, and merely denotes the general characteristics of topography and rainfall. Column A in table is prepared from observations of streams in southwest Missouri, eastern Kansas, western Arkansas and the southeastern portion of the Indian Territory. In all of this region, steep rocky slopes prevail and the soil absorbs but a small percentage of the rainfalls, and indicates larger waterways than are required in western Kansas and the level portions of Missouri, Colorado and New Mexico or Western Texas. This table is based on data procured from different western railroads, and from actual surveys and on a 6 in. rainfall in 24 hours taken from Government statistics, with the understanding that most of it falls in 6 or 8 hours. and velocity under bridge or through opening is 10 ft. per second. From the above it is obvious that each waterway should be given a certain amount of individual consideration, and if it is desirable to depart from waterways in table, full explanation of conditions and reason for departure should be given.

Approved:

R. A. RUTLEDGE,
Chief Engineer.

See Vol. XI, No. 2, April, 1906, Journal Western Soc. of Engrs. for report on Dun's waterway table.
C. E. O., April 13, 1914.

Table 31.—New York Central and Hudson River R. R. Culverts for Small Drainage Areas

Steep, rocky ground. Acres	Flat cultivation, long valley. Acres	Size. Diameter in inches	Equivalent capacity. Pipes
5	10	10	
10	20	12	
20	40	16	
25	50	18	two 16-in. pipes
30	60	20	two 16-in. pipes
45	90	24	two 18-in. pipes
70	140	30	two 24-in. pipes
110	220	36	two 30-in. pipes
150	300	42	two 30-in. pipes
180	360	48	two 36-in. pipes
280	560	60	

Note.—To be used only in the absence of more reliable information particularly existing culverts over the same stream.

Table 32.—Culvert Design. Iowa State Highway Commission

Size of culvert opening, ft.	Maximum acres	Minimum acres
2 × 2	70	28
4 × 4	376	140
6 × 6	1300	520
8 × 8	2700	1120
10 × 10	5000	2000

portioned to the runoff but for small areas the size is determined by the convenience of cleaning rather than by the discharge capacity. Where sufficient fall can be obtained to make the culvert self-cleaning, a 12 in. pipe is feasible under shallow fills but where the flow is sluggish, nothing less than a 16 or 18 in. pipe will serve satisfactorily. Long culverts under deep fills should never be smaller than 2 ft. wide and 3 ft. high to permit cleaning by hand if necessary.

The self-cleansing velocity of flow for sand and earth particles is about 1 ft. per second; for coarse gravel about 3 ft. per second (Ogden's Sewer Design, page 134). A pipe laid on a slope that gives a velocity of 5 ft. per second when flowing one quarter full should keep clean. This requires a fall of approximately

2 ft. per hunderd for a 12 in. pipe and is the minimum grade at which the 12 in. size should be used.

It is probable that a culvert should have the same slope as the stream bed. If given a greater slope the outlet end tends to clog and if a lesser the inlet end will plug. It is unusual for culverts to fill badly except when placed at the foot of a steep hillside where the stream velocity is naturally reduced. At such points an extra large structure should be designed with the idea of providing sufficient waterway even after the contraction caused by this settlement has occurred. Such a culvert should be cleaned after each freshet. The use of short paved dips in the roadway at such points in place of culverts is not advised as they are dangerous and cause accidents unless very gradual.

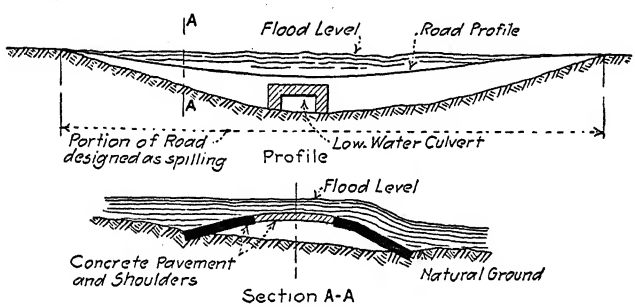


FIG. 100.

A man not familiar with the road often loses control of his car.

If, however, too much trouble is experienced in carrying large infrequent floods under the road a small culvert can be used for the low water flow which does not as a rule carry much silt and the flood flow can be carried over the roadbed by paving the entire surface with concrete from toe of slope to toe of slope and giving the longitudinal road profile a slight dip safe for traffic to localize the flooded portion of the road. (Fig. 100).

More trouble is experienced from culverts becoming filled with ice due to alternate freezing and thawing weather. This is particularly true of small culverts draining springs. Culverts as large as 2 $\times$ 2 have frozen solid in this manner and if this difficulty is anticipated the size should be regulated accordingly or trouble will be experienced during the spring break up. The following ingenious expedient has been successfully used on roads where the culverts fill with ice and snow during the

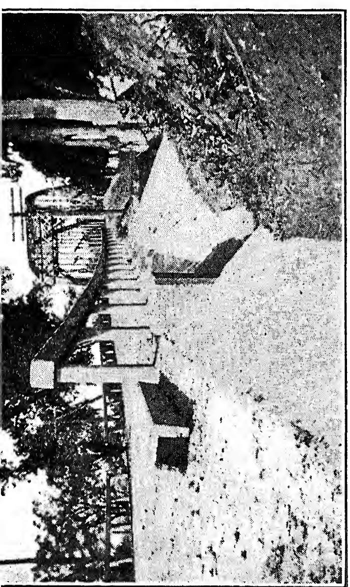


FIG. 101*A*.—In times of high water this road is covered to a depth of 5 to 7 ft. Note the low water culvert, concrete shoulders to prevent scour, and concrete guard rail protection.

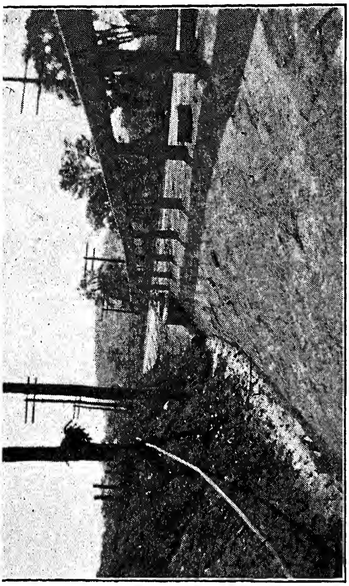


FIG. 101*B*.—Same as 101*A* looking in opposite direction.

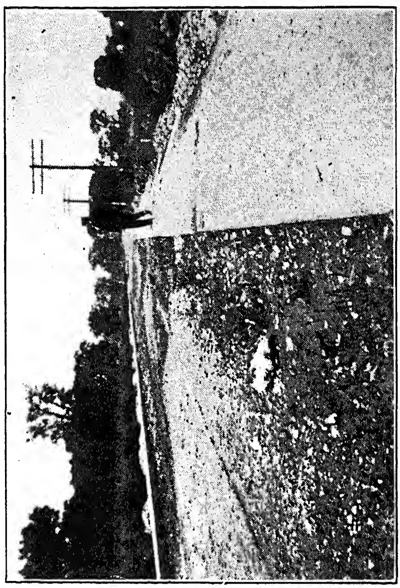


FIG. 101*C*.—Central portion of pavement not yet constructed. Concrete shoulders in place.

FIG. 101.—State Road across Genesee River Flat, New York State.

winter. A small pipe is suspended inside of the normal culvert. In the fall this small pipe is plugged and in the spring just as the snow begins to melt the plugs are removed and the first water flowing through the small pipe melts the ice and snow rapidly for the entire length of the culvert so that it is generally completely free to handle the main spring runoff.

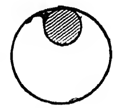


FIG. 102.—Small pipe in culvert.

Grade and Elevation of Inverts.—As previously stated it is desirable to prevent silting up of the culvert due to abrupt changes in the velocity of flow. For this reason culverts are normally given the same slope as the stream bed.

The elevation of the invert is always made low enough to drain all surface water from the upstream adjacent lands and if the elevation of the outlet permits it is desirable to make the culvert low enough to act as an outlet for farm underdrains. In hilly country underdrainage need not be given much weight but in flat country it often controls the elevation of the culvert invert.

In order to prevent serious ponding and damage to crops in flat country, all culverts or bridges on channels of any importance should be placed at such an elevation that the top of the waterway opening is as low or lower than the surrounding farm land. That is, the culvert elevation and shape of opening is designed for the hydraulic grade of maximum flood flow.

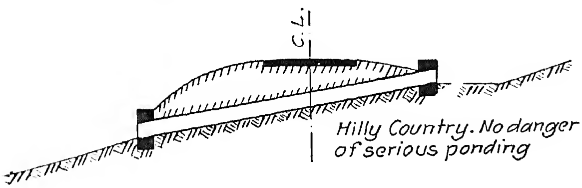


FIG. 103.

Figure 104 illustrates this point. The waterway areas of two culverts A and B are the same in size. However in order to get the full capacity of A the water would have to back up and overflow the surrounding lands. Culvert B carries the flood flow without serious ponding.

The use of bridge openings similar to A is very common practice in both railroad and highway design as it generally cheapens the culvert but is undesirable as causing needless damage to the abutting properties.

Depth of Cushion under Pavement.—A cushion of earth between the top of a concrete culvert or pipe and the bottom of the pavement is desirable. This is more important where the pavement is a rigid type such as brick or concrete than where it is a macadam construction.

The depth of this cushion sometimes controls the culvert invert elevation where the topography and road grade makes a low invert needlessly expensive or impracticable.

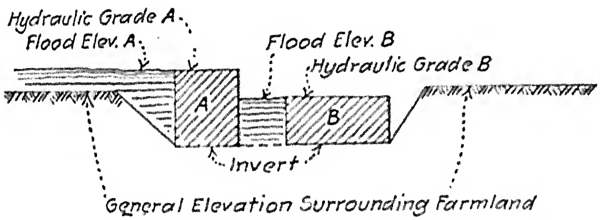


FIG. 104.

For rigid pavements the minimum desirable depth of cushion is approximately 6 in.; if less than this is used the chances are that the pavement will crack over the side walls of the culvert unless the pavement base is specially thickened and reinforced with steel. For macadam pavements a 6 in. cushion is desirable but no great damage occurs if the bottom course is laid directly on the culvert top. Even with a cushion settlement often develops each side of culverts having less than 2 to 3 ft. of cover but it can be easily fixed by the maintenance gang.

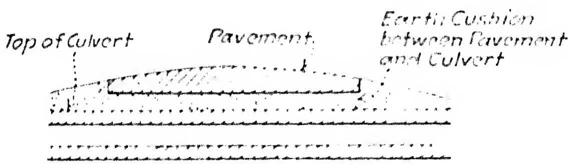


FIG. 105.

(*d*) **Dead and Live Loads.**—Dead loads are readily determined but reasonable live loads are a matter of judgment. Many of the states limit a vehicle load to 15 tons on improved roads without special permission but loads in excess of this occur now and then. The old culverts and bridges on our roads are practically without exception too light for modern traffic. Permanent culverts should be designed to carry the dead load plus a 20 ton vehicle load with 25 per cent. impact. Standard

culverts often seem needlessly strong but small concrete culverts are generally backfilled and used during construction before they develop their full strength and practical considerations require the excess material. A design load of a 20 ton vehicle with 30 per cent. impact is desirable for small permanent solid floor bridges of 10 ft. to 50 ft. span and this loading is often used for even timber bridges in states similar to Wyoming where oil development, etc., requires the movement of heavy machinery, although usually where timber is used a 10 ton live load with 50 per cent. impact is considered good practice and for mountain roads 6 tons will usually be acceptable. For long span solid floor steel or masonry structures a live load of 150 lb. per sq. ft. plus a 20 ton vehicle with 30 per cent. impact is first class modern practice. This value is higher than generally used.

These loadings are safe for military purposes as the following statement of Major General W. M. Black, Chief of Engineers 1917 will show.

"Our existing ordinance liable to accompany a field army will have its heaviest representative in a 12-inch howitzer weighing about 27,000 lb., 18,600 lb. of which are on the front wheels. The base or distance between the front and rear axles is 18 ft., width of track 7 ft. 4 in., width of tire 8 inches; width of tire shoes 12 inches. This howitzer is drawn by a 75 hp. caterpillar tractor weighing 25,000 lb. Comparison with the largest present day commercial trucks shows that a road or bridge substantial enough for such will suffice for the ordinance load."

The safe load for steel I beams, timber, reinforced concrete beams and slabs are given in the third book of this series.

(*c*) **Length of Structure.** Culverts are made long enough to accommodate the normal road section. There is nothing more unsightly or dangerous than the narrowing of the normal section at a culvert. First class design widens the section at culvert locations and even with minimum head room uses a clear roadway width between parapets of not less than 20 ft. on single track roads and not less than 26 ft. on double track roads. Short span permanent bridges up to about 25 ft. span on high type road improvements may well have a clear width of not less than 22 ft. between parapets. Above 25 ft. spans the roadway width depends largely on the location of the structure and probable traffic but for most main roads a 20 ft. clear roadway is satisfactory for permanent structures and a 16 ft. roadway for

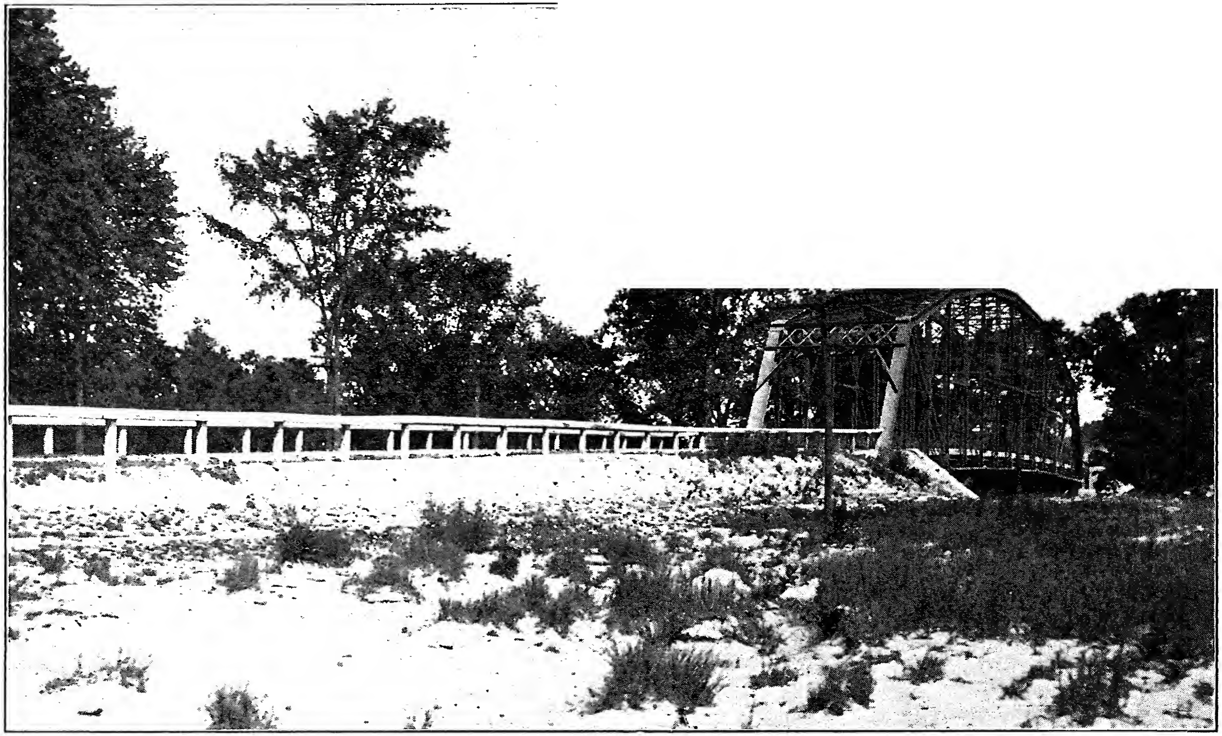


FIG. 106.—Modern solid floor highway bridge. Well designed approach protected with substantial concrete guard rail (Monroe Co., New York). Span 230 ft. roadway 19 ft. wide. Designed for a live load of 150 lbs. per sq. ft. plus a 20-ton traction engine. Approximate cost (1920) $50,000. Actual cost (1912) $22,000.

temporary timber structures. Figures 114 to 128 illustrate current practice.

(*f*) **Economical Type of Structure.**—The selection of type for any particular structure depends on the foundation soil, the requirements of topography and the relative economy of the different designs suitable for the location.

On dry firm foundations any type is satisfactory. On wet or moderately soft soils tile or concrete pipe culverts should be cradled in concrete; the concrete box type of culvert is probably more desirable for these conditions as the load is transmitted vertically in well defined directions. On quicksand or muck foundations the flat slab vertical side wall box type with timber sub foundation or pile and grillage is in general favor. Considering the usual foundation conditions the author prefers the flat slab or girder type of small span bridge in most cases unless there is a noticeable economy in some other form.

For small drainage areas some form of pipe culvert is generally used which will be discussed later in more detail.

From 2 ft. to 5 ft. spans the box culvert type is popular.

From 5 ft. to 20 ft. spans the slab, stringer or parapet girder form of construction is reasonable except under deep fills where the semicircular arch is better practice; from 20 ft. to 50 ft. spans pony truss or parapet girder types are available for most conditions or arches where the foundation is suitable. Pony trusses are desirable up to about 80 ft. span and beyond that the through Truss type.

The following list illustrates the practice of the Iowa Highway Commission.

1. Box culverts and slab bridges 2 to 20 ft. span. Not economical over 20 ft. span.
2. Reinforced concrete arches 8 to 100 ft. span. Foundation must be excellent.
3. Pony truss steel bridges with solid concrete floor 30 to 80 ft. spans.
4. Reinforced concrete girders 20 to 50 ft. span. Very economical but require careful design and construction. Not economical over 50 ft. span.

In the matter of type the author desires to emphasize the desirability of simple design particularly for small structures. Mass concrete for sides and bottoms is preferable to thin reinforced sections (see New York Standards, page 246). It may not be as scientific or theoretically as cheap but better results

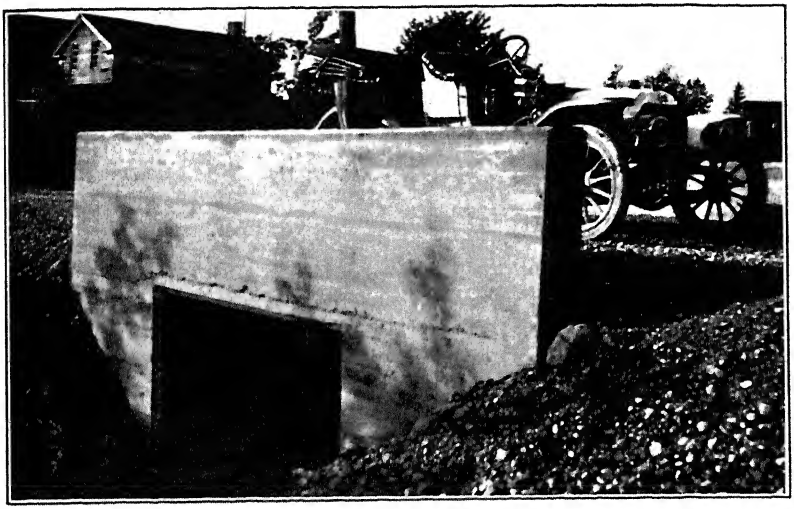


FIG. 107.—Simple concrete box culvert with straight high parapets (Town road construction).

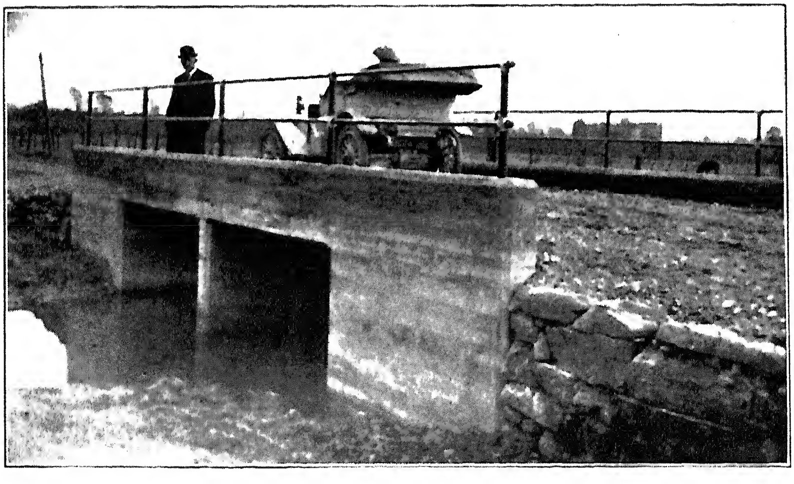


FIG. 108.—Double box culvert (town road construction).

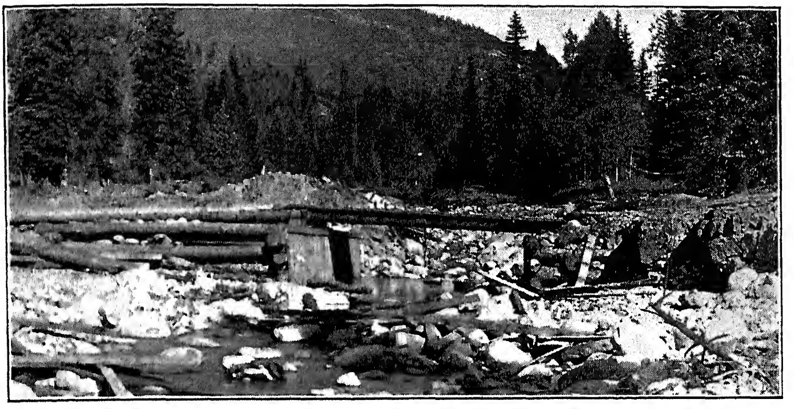


FIG. 109.—A crude log stringer bridge. Pioneer road work.

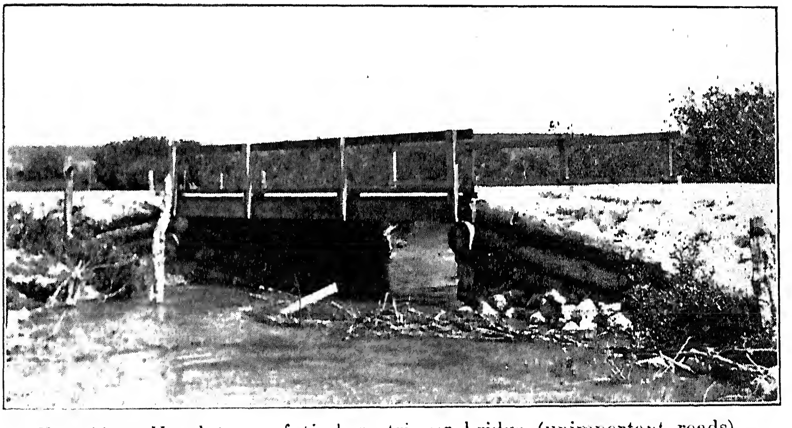


FIG. 110.—Usual type of timber stringer bridge (unimportant roads).

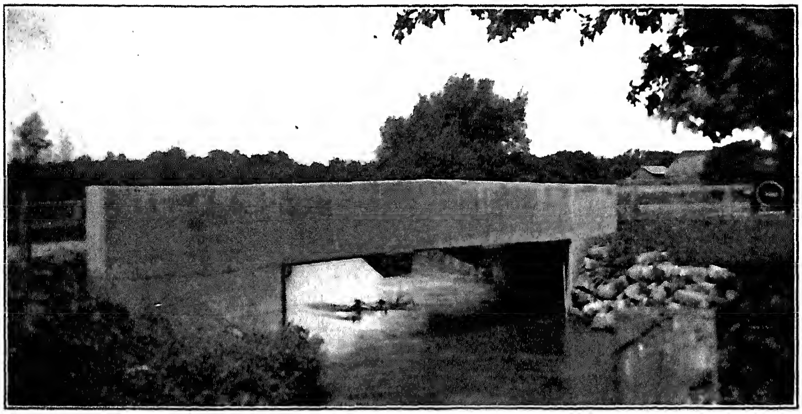


FIG. 111.—Parapet girder bridge (concrete). High class road. Span 25 ft. Width of roading 22 ft. Approximate cost (1920) $5000. Actual cost (1914) $2300.

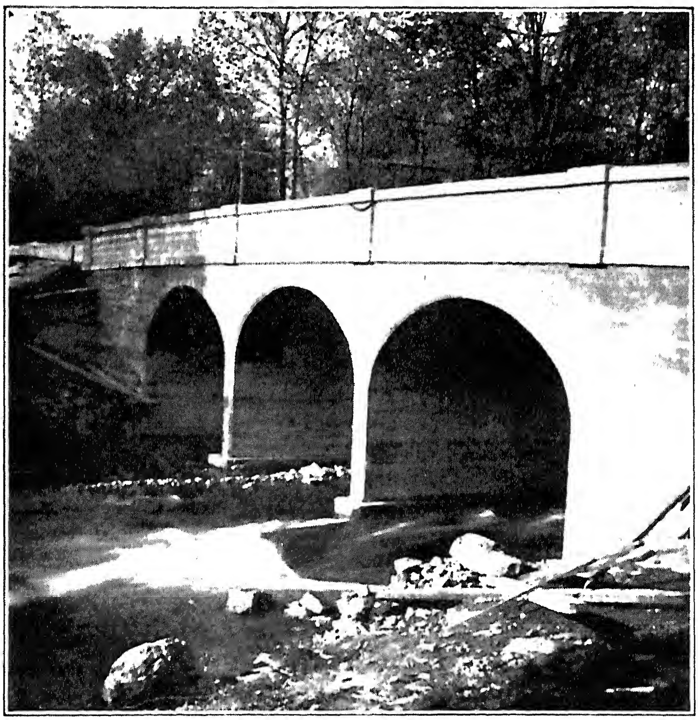


FIG. 112.—Arch type on rock foundation. This is a view of the bridge the plans of which are shown in detail in Fig. 128. Total span 50 ft. Approx. cost (1920) $5000. Actual cost (1915) $2500.

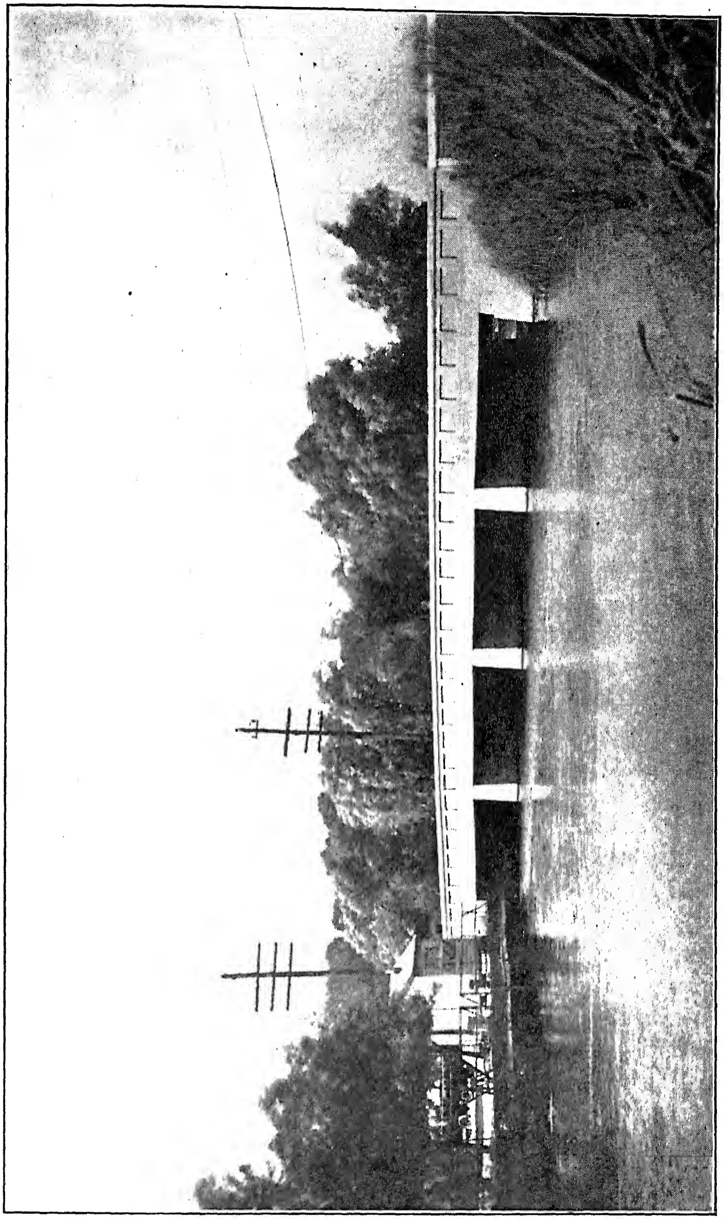


FIG. 113.—Flat reinforced concrete slab type on pile sub-foundation. Built in 1920. Cost $20,000. Total span 88 ft. Details of this bridge shown in Fig. 126.

are obtained with the usual inspectors. Road commissioners often do not understand the object of the reinforcement and either leave it out altogether or get it in the wrong place. For large structures where a competent inspector can be employed this objection does not hold but even for such structure mass concrete for abutments, retaining wall, etc., is to be preferred. Mass concrete 1 : 3 : 6, mixed with embedded boulders is satisfactory. Reinforced culvert concrete is usually made 1 : 2 : 4 mix.

Pipe Culverts.—The pipe culverts in common use are as follows (see Figs. 115 to 118, pages 241 to 244, for typical pipe):

CULVERT DESIGNS

Corrugated metal........................	Semi-permanent construction
Vitrified tile............................	Semi-permanent construction
Reinforced concrete pipe..................	Semi-permanent construction
Vitrified tile incased in concrete............	Permanent construction
Reinforced concrete pipe cradled in concrete.	Permanent construction
....	Permanent construction

ypes of culvert are suitable on firm foundations and r economical for small drainage areas. The relative cost will fluctuate for each contract which makes it impossible to generalize as to the economy of selection.

Box Culverts.—The two general types favored are the plain mass concrete bottom and side wall with reinforced cover slab and the lighter box reinforced on all sides (see Figs. 120 and 121).

Relative Economy of Culverts.—Comparative estimates of cost must be made for each contract but to give a general idea of the method of economical selection the following table is inserted for 1920 cost conditions prevailing in western New York.

The semi-permanent types should not be used on high class improvements except for driveway culverts.

Comparative estimates similar to Table 33 furnish a rational basis for judgment provided only the permanent types are compared and provided the comparison is made for each contract considering the special conditions prevailing due to location, market quotations on materials and local materials available.

For conditions similar to Table 33, Western New York, 1920 permanent pipe culverts are not economical over 18 in. in diameter. For drainage areas requiring a culvert waterway area of over 2 sq. ft. the box type is preferable. Of the box types the simple mass concrete structures are in the author's opinion more satis-

factory, considering construction difficulties than the thin wall reinforced type although they cost somewhat more than the thin sidewall type. This, however, is a matter of personal judgment.

TABLE 33.—APPROXIMATE RELATIVE COST OF PIPE AND BOX CULVERTS 30 FT. LONG INCLUDING HEADWALLS (EXCLUSIVE OF EXCAVATION)

Size culvert pipe, in.	Area waterway, sq. ft.	Style of construction					
		Corrugated metal	Vitrified tile	Vitrified tile incased in concrete	Reinforced concrete pipe	Reinforced concrete pipe cradled in concrete	Cast iron pipe
12	0.78	$60	$50	$65	$75	$90	$100
14	1.07	70	60	75	80	95	130
18	1.76	90	80	110	100	130	170
24	3.14	120	120	160	135	175	260
30	4.88	140	180	230	180	230	
36	7.05	170	260	310	240	290	
42	9.60	200	...	...	300	360	
48	12.52	230					

Size culvert opening span-height, ft.	Area waterway, sq. ft.	Style of construction, concrete boxes			
		Mass concrete bottom and sides (Fig. 120)		Thin Reinforced Sides and bottom (Fig. 121)	
		Total cost	Cost per sq. ft. waterway	Total cost	Cost per sq. ft. waterway
2 × 1.5	3	$160	$57		
2 × 2	4	190	50	$150	$35
3 × 2	6	210	37		
3 × 3	9	260	30	200	22
3 × 4	12	300	26		
4 × 2	8	250	31	230	30
4 × 3	12	300	25		
4 × 4	16	340	21	300	20
5 × 3	15	350	23		
5 × 4	20	400	20	350	17
5 × 5	25	450	18		

Examples of Current Practice in Pipe & Box Culverts.—The following cuts illustrate typical practice in small culvert design.

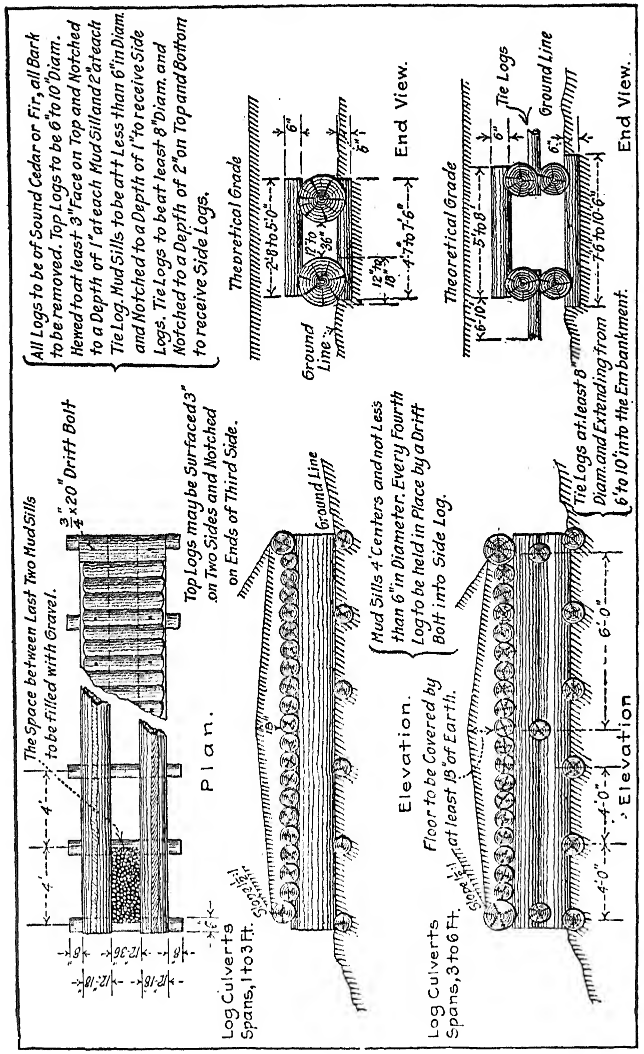


FIG. 114.—Typical log culverts, pioneer roads.

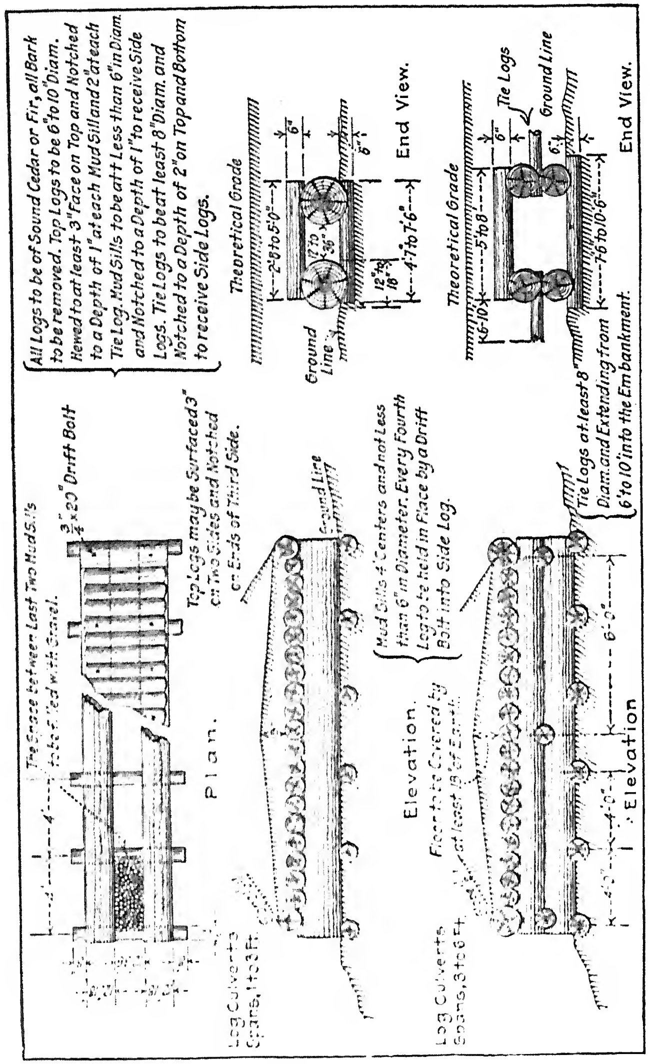


FIG. 114.—Typical log culverts, pioneer roads.

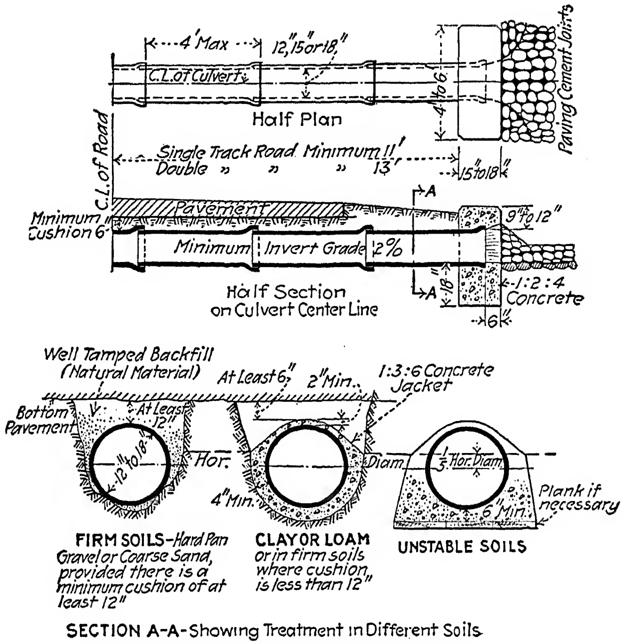


Fig. 116.—Typical vitrified pipe culverts.

Approximate Weights, Dimensions, Etc. of Standard Sewer Pipe

Calibre, in.	Price per foot	Weight, per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
12	$1.35	45	2¼	½	1
15	1.80	60	2½	½	1⅛
18	2.50	85	2¾	½	1¼
20	3.00	100	3	½	1⅜
22	4.00	130	3	½	1⅝
24	4.50	140	3¼	½	1⅝

Double Strength Pipe

Calibre, in.	Price per foot	Weight per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
15	$1.80	75	2½	½	1¼
18	2.50	118	2¾	½	1½
20	3.00	138	3	½	1⅔
22	4.00	157	3	½	1⅚
24	4.50	190	3¼	½	2

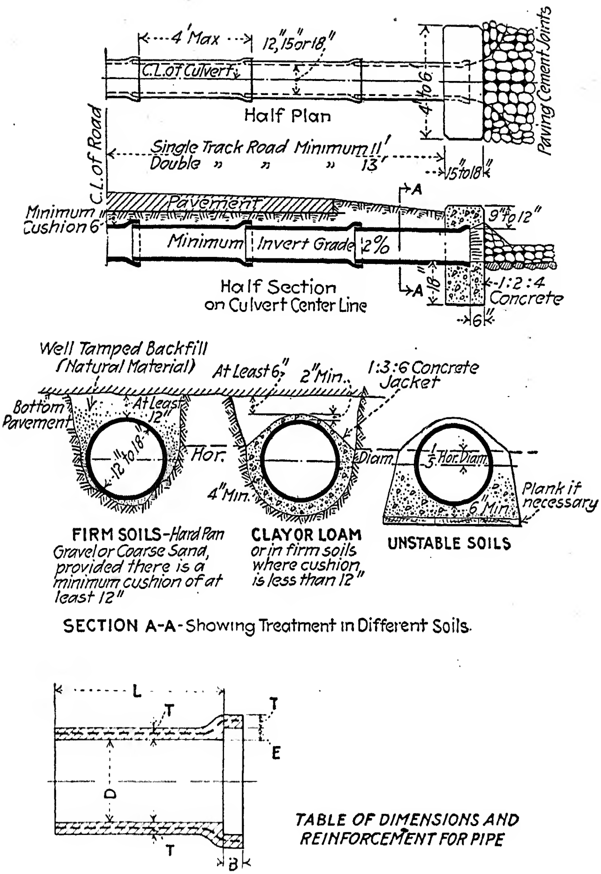


Table of Dimensions

D Inches	L-Max. Feet	T Inches	B-Min. Inches	E Inches
12	4	2	2½	2½
15	4	2	2½	2½
18	4	2½	3	3
24	4	3	3	3½
Effective Area of Circumferal Reinforcement Per Foot Length of Pipe				
12	0.058 Sq. Inches			
15	0.058 " "			
18	0.080 " "			
24	0.126 " "			
Approximate Weight Per Linear Foot of Pipe				
12	90 lbs			
15	110 "			
18	170 "			
24	260 "			

FIG. 117.—Typical reinforced concrete pipe culverts.

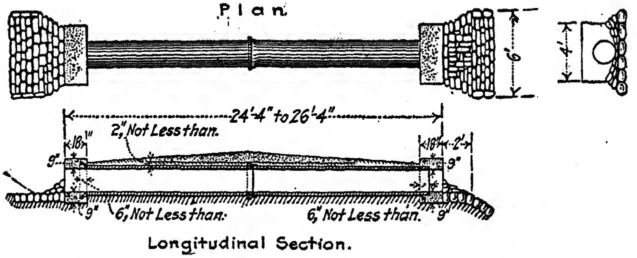


FIG. 118.—Cast iron pipe culvert. New York State standard.

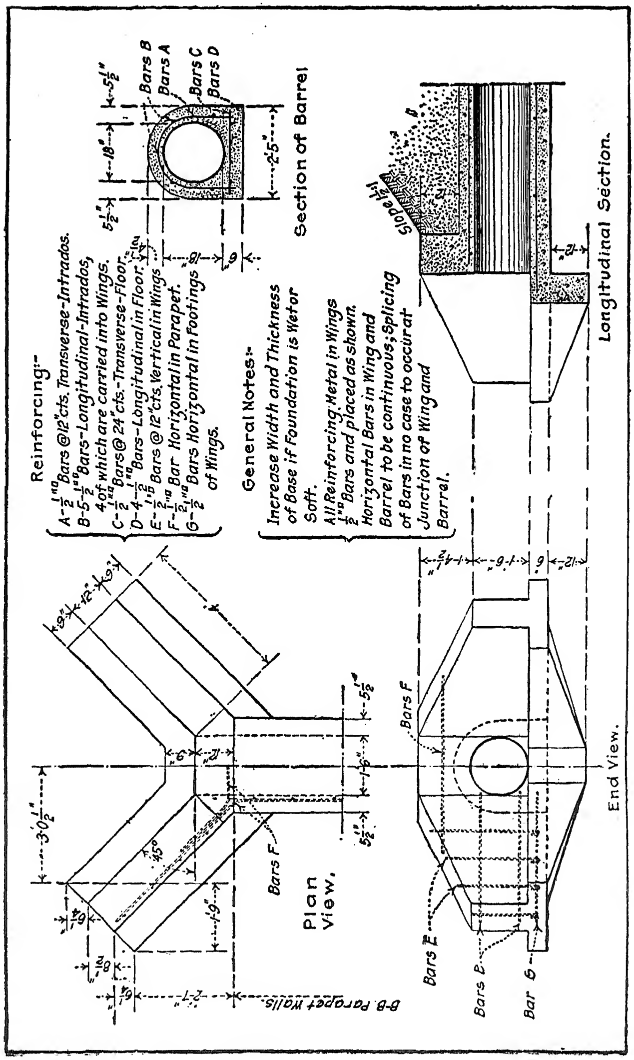


FIG. 119A.—State of Iowa 18 in. circular concrete culverts.

18 inch Circular Culvert.

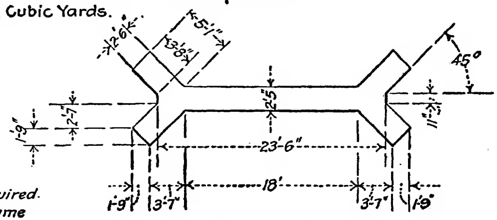
Bill of Reinforcing Steel and Quantities of Concrete Materials

Cubic Contents of Culvert 20 ft. Back to Back of Parapet Walls Equals, $5\frac{4}{10}$ Cubic Yards.

Concrete Materials.

Item	Quantity Req. for Culvert 20 ft. b-b. Parapet Walls.	Additional Amount per Ft. Additional Length of Barrel
	If Sand and Stone are Used.	
Sand	2.38 Cu. Yds.	0.055 Cu. Yds
Stone	4.80 " "	0.112 " "
Cement	7.9 bbls. or 31.6 Sack	0.182 bbls. or 0.73 Sacks
	If Gravel alone is Used.	
Gravel	6.2 Cu Yds	0.125 Cu. Yds
Cement	10.25 bbls. or 41.0 Sacks	0.238 bbls. or 0.95 Sacks

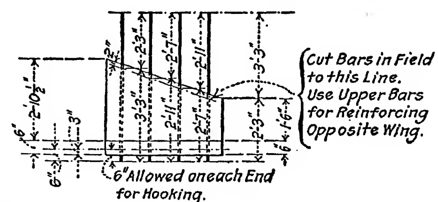
Note { The Table above gives Theoretical Quantities required. To allow for Shrinkage add 20 Per Cent to the Volume of Sand and Stone or Gravel given in Table.



Staking Diagram.

Bill of Reinforcing for Culvert.
20 ft. b-b. Parapet Walls.

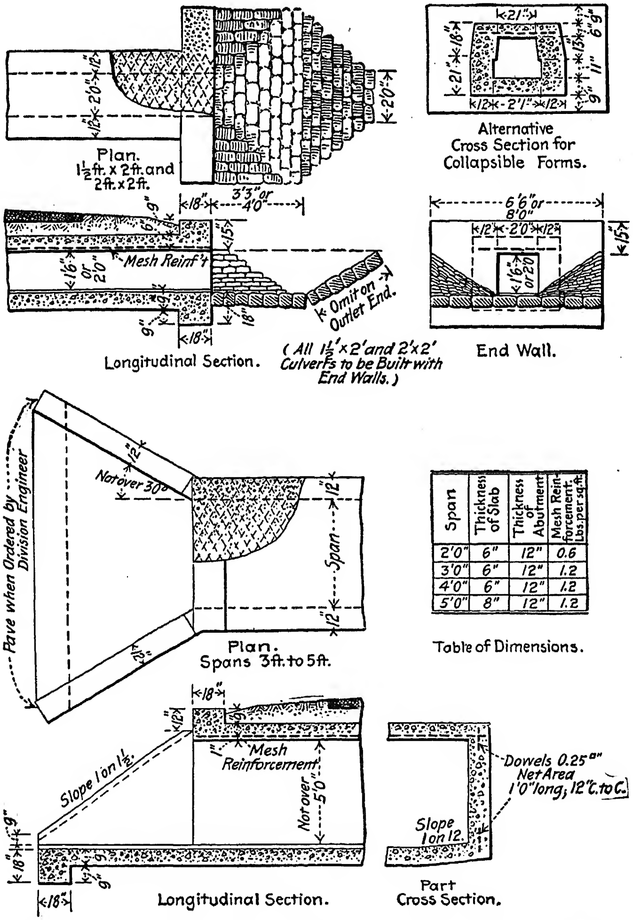
Mark	Position	No.	Size	Length	Weight	Remarks
A	Transverse Barrel	22	½" Sq.	4'-10"	90 lb.	
B	Longitud. Barrel	4	"	28'-6"	97 "	Continued into Wings
B	Longitud. Barrel	1	"	21'-6"	18 "	Center Bar
C	Transverse Floor	12	"	2'-3"	23 "	
D	Longitud. Floor	4	"	23'-0"	78 "	Cut in Field per Sketch
E	Vertical Wings	8	"	5'-6"	38 "	Continued into Wings
F	Horizont. Parapet	2	"	5'-6"	9 "	
G	Horizont. Footings	4	"	4'-0"	14 "	
	Total Reinforcing Steel				367 lb	



Elevation of Wing.

Note: { For each additional Foot of Barrel use one additional Bar "A," One Half Bar "C," increase Length of Bars "B" and "D" by One Foot.

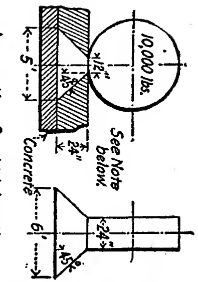
Fig. 119B.—State of Iowa 18 in. circular concrete culverts.



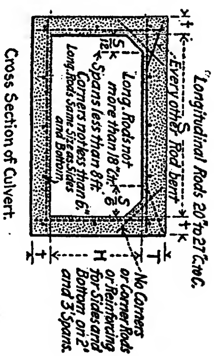
Span	Thickness of Slab	Thickness of Abutment	Mesh Reinforcement Lbs. per sq. ft.
2'0"	6"	12"	0.6
3'0"	6"	12"	1.2
4'0"	6"	12"	1.2
5'0"	8"	12"	1.2

For effect of depth of fill on thickness of cover slab see Volume 3.

FIG. 120.—New York State small box culverts.



Assumption for Live Load.



Cross Section of Culvert.

TABLE FOR STANDARD CULVERTS. Loading 15-Ton Road Roller, 10,000 lbs. on each wheel. Unit stresses 16,000 lbs. for Steel, 600 lbs. for Concrete, 0.7% of Steel. Los Angeles Co. Highway Com., A. E. Loder, Chief Eng.

				Top Reinforcement			Corner Reinforcement			Side Walls Reinforcement			Bottom Reinforcement			Quan. per lineal ft. box.		
D[1]	H[2]	T[3]	t[4]	Size	Spc.	Lgth.	Size	Spc.	Lgth.	Size	Spc.	Lgth.	Size	Spc.	Lgth.	C. Yds Con.	Steel lb.	
8"	1'	4"	4"	3/8"	8"	2'-6"										.091	3.70	2'-Span
8"	2'	4"	4"	3/8"	8"	2'-6"										.115	3.70	
8"	1'	5 1/2"	5"	3/8"	5"	3'-9"										.155	7.17	3'-Span
8"	2'	5 1/2"	5"	3/8"	5"	3'-9"										.186	7.17	
8"	3'	5 1/2"	5"	3/8"	5"	3'-9"										.216	8.12	
8"	1'	6"	5"	1/2"	8"	4'-8"	3/8"	16"	1'-6"	3/8"	16"	1'-9"	3/8"	16"	4'-8"	.204	12.83	4'-Span
8"	2'	6"	5"	1/2"	8"	4'-8"	3/8"	16"	1'-6"	3/8"	16"	2'-9"	3/8"	16"	4'-8"	.235	13.55	
8"	3'	6"	5"	1/2"	8"	4'-8"	3/8"	16"	1'-6"	3/8"	16"	3'-9"	3/8"	16"	4'-8"	.266	15.22	
8"	2'	6 1/2"	5"	1/2"	7"	5'-8"	3/8"	14"	1'-6"	3/8"	14"	2'-9"	3/8"	14"	5'-8"	.278	17.91	5'-Span
8"	3'	6 1/2"	5"	1/2"	7"	5'-8"	3/8"	14"	1'-6"	3/8"	14"	3'-9"	3/8"	14"	5'-8"	.309	19.68	
8"	4'	6 1/2"	5"	1/2"	7"	5'-8"	3/8"	14"	1'-6"	3/8"	14"	4'-9"	3/8"	14"	5'-8"	.339	20.49	
8"	2'	7 1/2"	6"	1/2"	6"	6'-10"	3/8"	12"	1'-9"	3/8"	12"	3'-0"	3/8"	12"	6'-10"	.373	23.23	6'-Span
8"	3'	7 1/2"	6"	1/2"	6"	6'-10"	3/8"	12"	1'-9"	3/8"	12"	4'-0"	3/8"	12"	6'-10"	.410	25.14	
8"	4'	7 1/2"	6"	1/2"	6"	6'-10"	3/8"	12"	1'-9"	3/8"	12"	5'-0"	3/8"	12"	6'-10"	.448	26.10	
8"	2'	8 1/2"	6"	5/8"	8"	8'-10"	1/2"	16"	2'-0"	1/2"	16"	3'-2"	1/2"	16"	8'-10"	.494	38.32	8'-Span
8"	3'	8 1/2"	6"	5/8"	8"	8'-10"	1/2"	16"	2'-0"	1/2"	16"	4'-2"	1/2"	16"	8'-10"	.531	41.30	
8"	4'	8 1/2"	7"	5/8"	8"	9'-0"	1/2"	16"	2'-0"	1/2"	16"	5'-2"	1/2"	16"	9'-0"	.628	43.02	
8"	5'	8 1/2"	7"	5/8"	8"	9'-0"	1/2"	16"	2'-0"	1/2"	16"	6'-2"	1/2"	16"	9'-0"	.671	46.00	
8"	2'	10"	7"	5/8"	6 1/2"	11'-0"	1/2"	13"	2'-6"	1/2"	13"	3'-3"	1/2"	13"	11'-0"	.700	54.90	10'-Span
8"	3'	10"	7"	5/8"	6 1/2"	11'-0"	1/2"	13"	2'-6"	1/2"	13"	4'-3"	1/2"	13"	11'-0"	.742	58.17	
8"	4'	10"	7"	5/8"	6 1/2"	11'-0"	1/2"	13"	2'-6"	1/2"	13"	5'-3"	1/2"	13"	11'-0"	.786	59.74	
8"	5'	10"	8"	5/8"	6 1/2"	11'-2"	1/2"	13"	2'-8"	1/2"	13"	6'-4"	1/2"	13"	11'-2"	.900	63.90	
8"	6'	10"	8"	5/8"	6 1/2"	11'-2"	1/2"	13"	2'-8"	1/2"	13"	7'-4"	1/2"	13"	11'-2"	.949	65.47	
8"	7'	10"	8"	5/8"	6 1/2"	11'-2"	1/2"	13"	2'-8"	1/2"	13"	8'-4"	1/2"	13"	11'-2"	1.000	68.74	
8"	8'	10"	8"	5/8"	6 1/2"	11'-2"	1/2"	13"	2'-8"	1/2"	13"	9'-4"	1/2"	13"	11'-2"	1.048	70.31	
8"	2'	11"	8"	5/8"	6"	13'-2"	1/2"	12"	3'-0"	1/2"	12"	3'-7"	1/2"	12"	13'-2"	.916	69.31	12'-Span
8"	3'	11"	8"	5/8"	6"	13'-2"	1/2"	12"	3'-0"	1/2"	12"	4'-7"	1/2"	12"	13'-2"	.965	72.71	
8"	4'	11"	8"	5/8"	6"	13'-2"	1/2"	12"	3'-0"	1/2"	12"	5'-7"	1/2"	12"	13'-2"	1.014	74.41	
8"	5'	11"	8"	5/8"	6"	13'-2"	1/2"	12"	3'-0"	1/2"	12"	6'-7"	1/2"	12"	13'-2"	1.063	77.81	
8"	6'	11"	9"	5/8"	6"	13'-4"	1/2"	12"	3'-0"	1/2"	12"	7'-6"	1/2"	12"	13'-4"	1.205	79.94	
8"	7'	11"	9"	5/8"	6"	13'-4"	1/2"	12"	3'-0"	1/2"	12"	8'-6"	1/2"	12"	13'-4"	1.261	83.34	
8"	8'	11"	9"	5/8"	6"	13'-4"	1/2"	12"	3'-0"	1/2"	12"	9'-6"	1/2"	12"	13'-4"	1.316	85.04	
8"	9'	11"	9"	5/8"	6"	13'-4"	1/2"	12"	3'-0"	1/2"	12"	10'-6"	1/2"	12"	13'-4"	1.372	88.44	
8"	10'	11"	9"	5/8"	6"	13'-4"	1/2"	12"	3'-0"	1/2"	12"	11'-6"	1/2"	12"	13'-4"	1.427	90.14	

[1] Depth of fill. [2] Height of Culvert. [3] Thickness of Top. [4] Thickness of Bottom and Sides. NOTE: This table is calculated for a minimum fill of 8 in. of rocks over Culvert slabs and is correct for all fills up to 6 ft. in height.

FIG. 121.

SMALL SPAN BRIDGES

Economic small span bridge design is susceptible to considerable variation of type.

Size of waterway, width of roadway; live and dead loading have been outlined.

The superstructure up to a span of 25 ft. is generally the slab or reinforced concrete parapet girder design on high class roads and the timber stringer on king post truss design on pioneer roads. Figures 122 to 128 illustrate current practice. George C. Wright, bridge designer for Monroe County, New York, states that for conditions prevailing in this country the parapet girder type is more economical than the slab design for spans greater than 10 to 15 ft. The parapet girder type should not however be used unless the construction inspection is intelligent and rigid.

Foundation Soils.—The foundation design and to a certain extent the type of superstructure is affected by the soil. Most ordinary soils afford satisfactory foundations for small span bridges but piles must be used for muck or quicksand and are advisable if much scour is anticipated which can not be prevented by rip rap protection. Pile foundations are required for all large structures where rock foundations are not available and are desirable for any concrete structure over 30 ft. span.

Where much ice occurs piers in small streams should be avoided. They can be used to advantage to reduce cost, however, if there is no danger of ice or débris jams particularly if the flow is sluggish and in the latter case for wide shallow streams the trestle design is appropriate.

The safe foundation load on various soils recommended by "Baker's Foundations" are as follows:

Rock (poor)	5	tons per sq. ft.
Rock (solid and first quality)	25	tons per sq. ft.
Dry clay	4	tons per sq. ft.
Medium dry clay	2	tons per sq. ft.
Soft clay	1	ton per sq. ft.
Cemented gravel	8	tons per sq. ft.
Compact sand	4	tons per sq. ft.
Clean dry sand	2	tons per sq. ft.
Quicksand and alluvial soil	½	ton per sq. ft.

Pile Loading.—Where piles are used for types of construction where slight settlement is not objectionable (slab, girder or truss

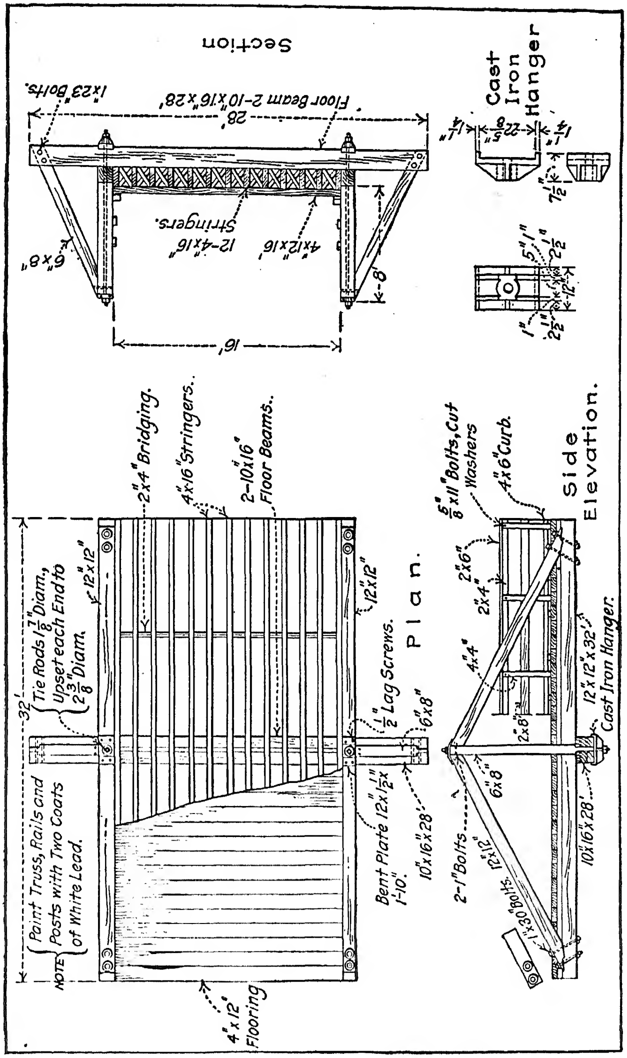
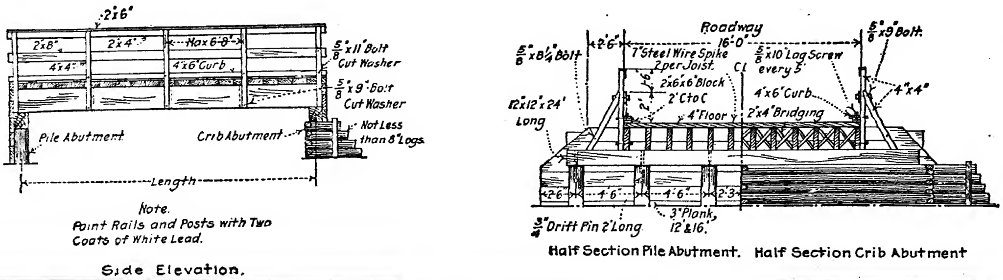


FIG. 122.—30 ft. span king post timber bridge. State of Wyoming.



Bill of Miscellaneous Material

For Standard Wooden Bridges 8' to 20' Long. 16'–18'–20' Roadway.
Capacity: 20-ton Traction Eng. (⅔ on Rear Axle) + 25% Impact

Name	Road-way	Maximum Spans of Joists				
		20'-0" E. to E. 19'-0" C. to C.	16'-0" E. to E. 15'-0" C. to C.	12'-0" E. to E. 11'-0" C. to C.	10'-0" E. to E. 9'-0" C. to C.	8'-0" E. to E. 7'-0" C. to C.
Bridging nails	Any	6#—10d	6#—10d	4#—10d	4#—10d	
Rail nails	Any	5#—40d	4#—40d	3#—40d	3#—40d	2#—40d
Floor spikes	16	80#— 7"	64#— 7"	48#— 7"	40#— 7"	32#— 7"
Floor spikes	18	80#— 7"	64#— 7"	48#— 7"	40#— 7"	32#— 7"
Floor spikes	20	88#— 7"	70#— 7"	53#— 7"	44#— 7"	35#— 7"
Curb lag screws	Any	10—5/8" × 10"	8—5/8" × 10"	6—5/8" × 10"	6—5/8" × 10"	6—5/8" × 10"
Rail bolts	Any	12—5/8" × 9"	12—5/8" × 9"	10—5/8" × 9"	10—5/8" × 9"	8—5/8" × 9"
Rail bolts	Any	8—5/8" × 11"	8—5/8" × 11"	6—5/8" × 11"	6—5/8" × 11"	4—5/8" × 11"
Rail bolts	Any	4—5/8" × 8 1/4"	4—5/8" × 8 1/4"	4—5/8" × 8 1/4"	4—5/8" × 8 1/4"	4—5/8" × 8 1/4"
Pressed washers	Any	64 for 5/8" bolts	62 for 5/8" bolts	50 for 5/8" bolts	50 for 5/8" bolts	42 for 5/8" bolts

All Nails and Spikes to be Steel Wire

Fig. 123.—Standard wooden bridges. State of Wyoming.

Name	Maximum Spans for Joists Shown				
	20′–0″ E. to E. 19′–0″ C. to C.	16′–0″ E. to E. 15′–0″ C. to C.	12′–0″ E. to E. 11′–0″ C. to C.	10′–0″ E. to E. 9′–0″ C. to C.	8′–0″ E. to E. 7′–0″ C. to C.
16′–0″ Roadway					
Joists	12—4″×18″×20′	12—4″×16″×16′	12—3″×16″×12′ or 12—4″×14″×12′	12—3″×14″×10′ or 12—4″×12″×10′	12—3″×12″×8′
Floor	22—4″×12″×16′	18—4″×12″×16′	14—4″×12″×16′	11—4″×12″×16′	9—4″×12″×16′
Bridging	9—2″×4″×16′	9—2″×4″×16′	5—2″×4″×16′	5—2″×4″×16′	
18′–0″ Roadway					
Joists	12—4″×18″×20′	12—4″×16″×16′	12—3″×16″×12′ or 12—4″×14″×12′	12—3″×14″×10′ or 12—4″×12″×10′	12—3″×12″×8′
Floor	22—4″×12″×18′	18—4″×12″×18′	14—4″×12″×18′	11—4″×12″×18′	9—4″×12″×18′
Bridging	10—2″×4″×16′	10—2″×4″×16′	6—2″×4″×16′	6—2″×4″×16′	
20′–0″ Roadway					
Joists	14—4″×18″×20′	14—4″×16″×16′	14—3″×16″×12′ or 14—4″×14″×12′	14—3″×14″×10′ or 14—4″×12″×10′	14—3″×12″×8′
Floor	22—4″×12″×20′	18—4″×12″×20′	14—4″×12″×20′	11—4″×12″×20′	9—4″×12″×20′
Bridging	12—2″×4″×16′	12—2″×4″×16′	7—2″×4″×16′	7—2″×4″×16′	
Any Roadway					
Curb	3—4″×6″×14′	2—4″×6″×16′	2—4″×6″×12′	2—4″×6″×10′	2—4″×6″×8′
Rail S. 4S.	4—4″×4″×16′	4—4″×4″×16′	3—4″×4″×16′	3—4″×4″×16′	2—4″×4″×16′
	2—2″×4″×20′	2—2″×4″×16′	2—2″×4″×12′	2—2″×4″×10′	2—2″×4″×8′
	2—2″×6″×20′	2—2″×6″×16′	2—2″×6″×12′	2—2″×6″×10′	2—2″×6″×8′
	2—2″×8″×20′	2—2″×8″×16′	2—2″×8″×12′	2—2″×8″×10′	2—2″×8″×8′
Blocks	22—2″×6″×6″	18—2″×6″×6″	14—2″×6″×6″	12—2″×6″×6″	10—2″×6″×6″

Table title: **Bill of Lumber** — For Standard Wooden Bridges 8′ to 20′ Long. 16′–18′–20′ Roadway. Capacity: 20-ton Traction Eng. (2/3 on Rear Axle) + 25% Impact

FIG. 123.—(*Continued*).

MATERIAL FOR ONE PILE ABUTMENT

Name	Roadway	Quantity	Size	Length or Kind
Piling	16'–18'	6	12" butt dia.	10'–0" in ground
Cap	Any	1	12" × 12"	24'–0"
Backing	Any	6 or more	3" × 12"	12'–0"
Backing	Any	6 or more	3" × 12"	16'–0"
Drifts	Any	6	¾" φ	2'–0"
Nails for backing plk.	Any	7½#	60d	Steel wire nails

Maximum Length C. to C.	Roadway		
	16'–0"	18'–0"	20'–0"
20'–0"	12—4" × 18"	12—4" × 18"	14—4" × 18"
16'–0"	12—4" × 16"	12—4" × 16"	14—4" × 16"
12'–0"	12—4" × 14"	12—4" × 14"	14—4" × 14"
11'–0"	12—3" × 16"	12—3" × 16"	14—3" × 16"
9'–0"	12—3" × 14"	12—3" × 14"	14—3" × 14"
8'–0"	12—4" × 12"	12—4" × 12"	14—4" × 12"
6'–0"	12—3" × 12"	12—3" × 12"	14—3" × 12"

FIG. 123.—(*Continued*).

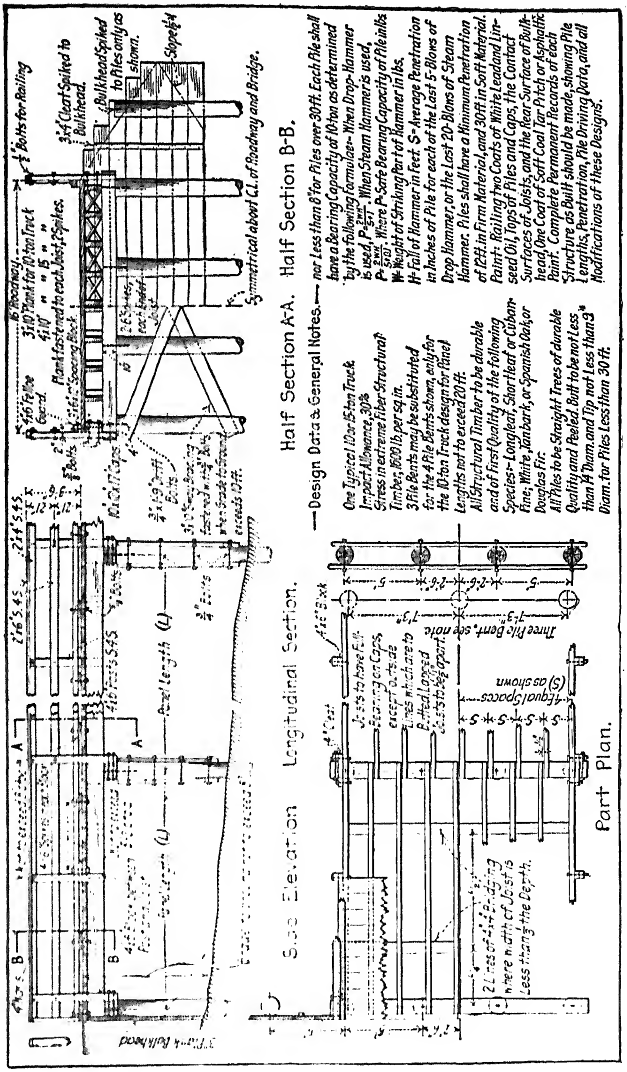


FIG. 124.—Typical Pile Trestle. U. S. Office of Public Roads.

Dimensions and Quantities for Superstructure
Capacity 15-Ton Truck

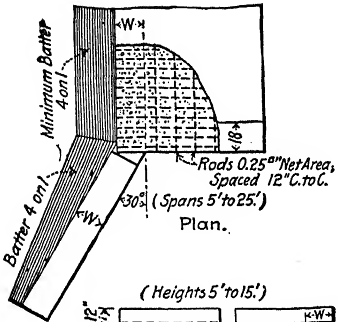
Panel Length (L)	Intermediate Panel				
	Size of Joists	Joists	Floor Railing Details	Total Lumber	Bolts, Washers, Spikes, Nails
Feet	Inches	Ft. B. M.	Ft. B. M.	Ft. B. M.	Pounds
10	6×12	590	800	1390	80
	4×14	460	840	1300	
11	6×12	650	870	1520	90
	4×14	500	920	1420	
12	6×12	700	940	1640	90
	4×16	620	990	1610	
	8×12	1010	1020	2030	
13	6×14	880	1020	1900	90
	4×16	670	1070	1740	
	8×12	1080	1090	2170	
14	6×14	950	1090	2040	90
	4×16	720	1140	1860	
15	8×12	1150	1170	2320	100
	6×14	1010	1170	2180	
16	10×12	1530	1240	2770	
	6×14	1070	1240	2310	100
	6×16	1230	1240	2470	
17	10×12	1620	1340	2960	
	8×14	1510	1340	2850	120
	6×16	1300	1340	2640	
18	10×12	1710	1410	3120	
	8×14	1600	1410	3010	130
	6×16	1370	1410	2780	
19	10×12	1800	1490	3290	
	8×14	1680	1490	3170	130
	6×16	1440	1490	2930	
20	8×14	1760	1560	3320	130
	8×16	2020	1560	3580	
21	10×14	2310	1640	3950	140
	8×16	2110	1640	3750	
22	10×14	2410	1710	4120	150
	8×16	2210	1710	3920	

Dimensions and Quantities—Substructure

Grade to Ground	Sway Bracing—Intermediate Bent			
	Sets	Length	Lumber	Bolts
Feet	No. Reqd.	Feet	Ft. B. M.	Pounds
10–12	1	18	90	35
12–15	1	20	100	35
15–18	1	22	110	35
18–23	2	18 & 20	190	60
23–26	2	20	200	60
One cap 10″×12″×17′–0″			170	10

Grade to Ground	Bulkhead—End Bent	
	Lumber	Spikes
Feet	Ft. B. M.	Pounds
4	270	5
5	360	5
6	460	10
7	550	10
8	640	10

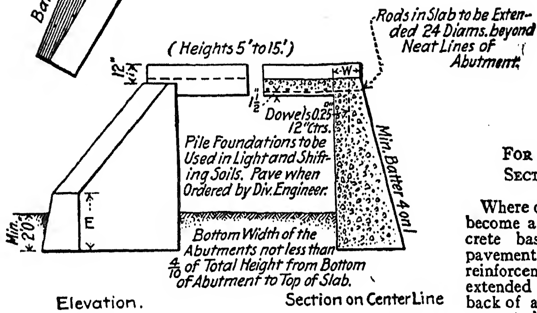
Fig. 124.—(*Continued*).



Note

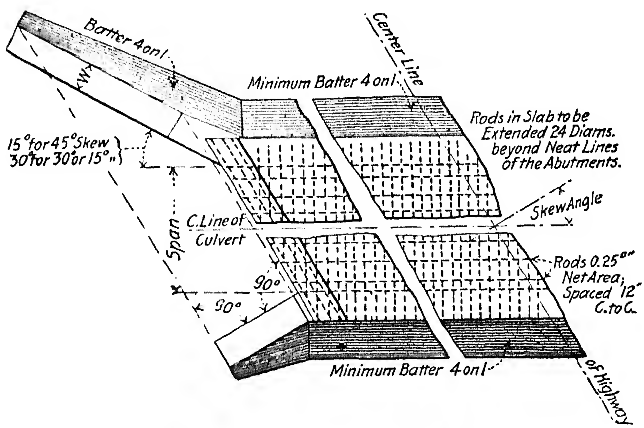
All rods to have a deformed cross-section. All rib metal to be of medium steel.

2d class concrete in all slabs and parapets. 3d class concrete in wings invert and abutments. Wing walls on the outlet end of all square culverts with concrete floors to be built parallel to the center line of the culvert. Round all exposed edges to 1½ inch radius.



For Typical Section "F"

Where culvert covers become a part of concrete base for brick pavement, transverse reinforcement should be extended 12" beyond back of abutment into concrete base.



Dimensions of slabs on page 256.

Fig. 125.—New York State slab bridges.

Span	Thickness of Slab*	Net Area of Rods	Rod Spacing C–C	Length of Dowels
5	8″	0.25sq.″	$4\frac{1}{2}$″	12″
6	9″	"	4″	"
7	10″	0.39sq.″	$5\frac{3}{4}$″	"
8	10″	"	$5\frac{1}{4}$″	"
9	11″	"	5″	"
10	12″	"	$4\frac{3}{4}$″	"
11	12″	0.56sq.″	$6\frac{1}{4}$″	"
12	13″	"	6″	18″
13	13″	"	$5\frac{3}{4}$″	"
14	14″	"	$5\frac{3}{8}$″	"
15	14″	"	5″	"
16	15″	"	$4\frac{3}{4}$″	"
17	15″	"	$4\frac{3}{4}$″	"
18	16″	"	$4\frac{1}{2}$″	"
19	17″	"	$4\frac{1}{4}$″	"
20	18″	0.77sq.″	$5\frac{1}{4}$″	"
21	18″	"	$5\frac{1}{4}$″	"
22	19″	"	5″	24″
23	19″	"	5″	"
24	20″	"	$4\frac{5}{8}$″	"
25	21″	1.00sq.″	$5\frac{7}{8}$″	"

For Spans 5′ to 19′ W = 18″ For Clear Height 10′ or less
" " 5′ to 19′ W = 24″ " " " 11′ to 15′
" " 20′ to 25′ W = 24″ " " " 15′ or less
For Clear Height 7′ or less E = 3′- 0″
" " " 8′ to 10′ E = 4′- 0″
" " " above 10′ E = 5′- 0″

* NOTE.—The thickness of slab given is for shallow fills. For the effect of deep fills see Volume III.

FIG. 125.—(*Continued*).

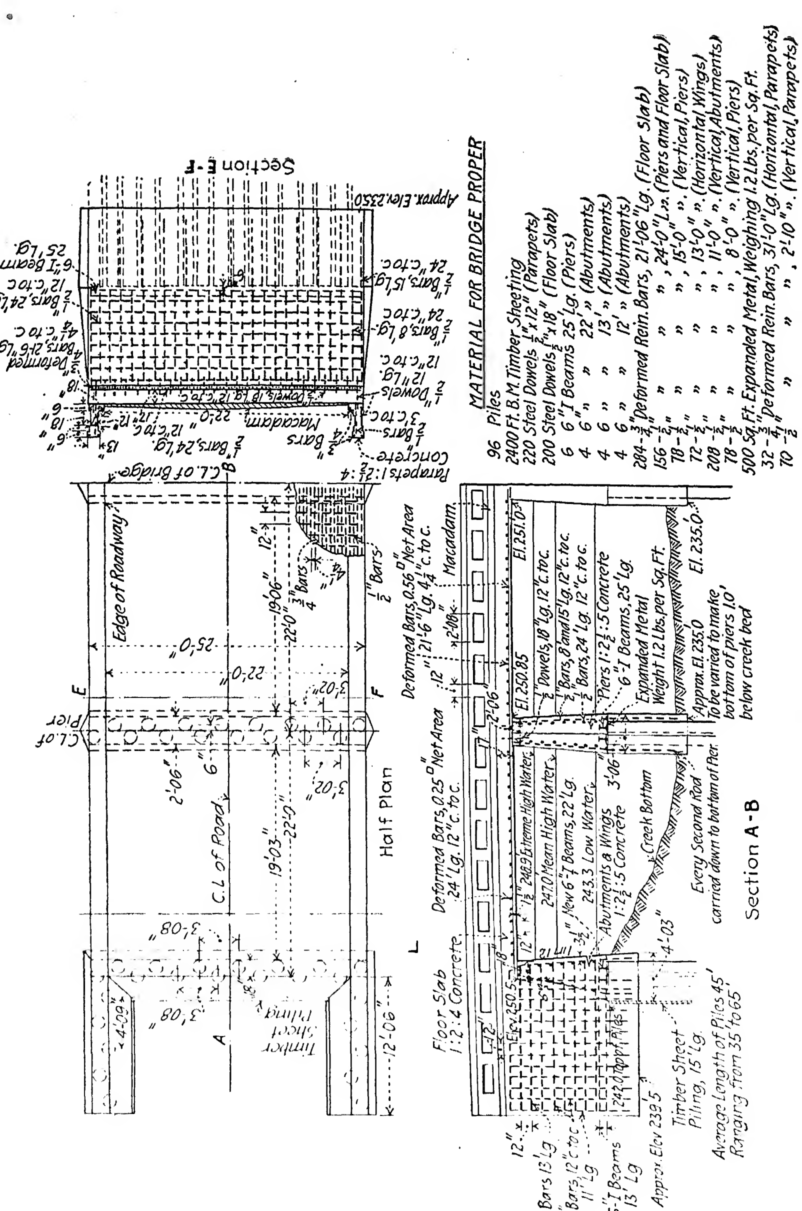
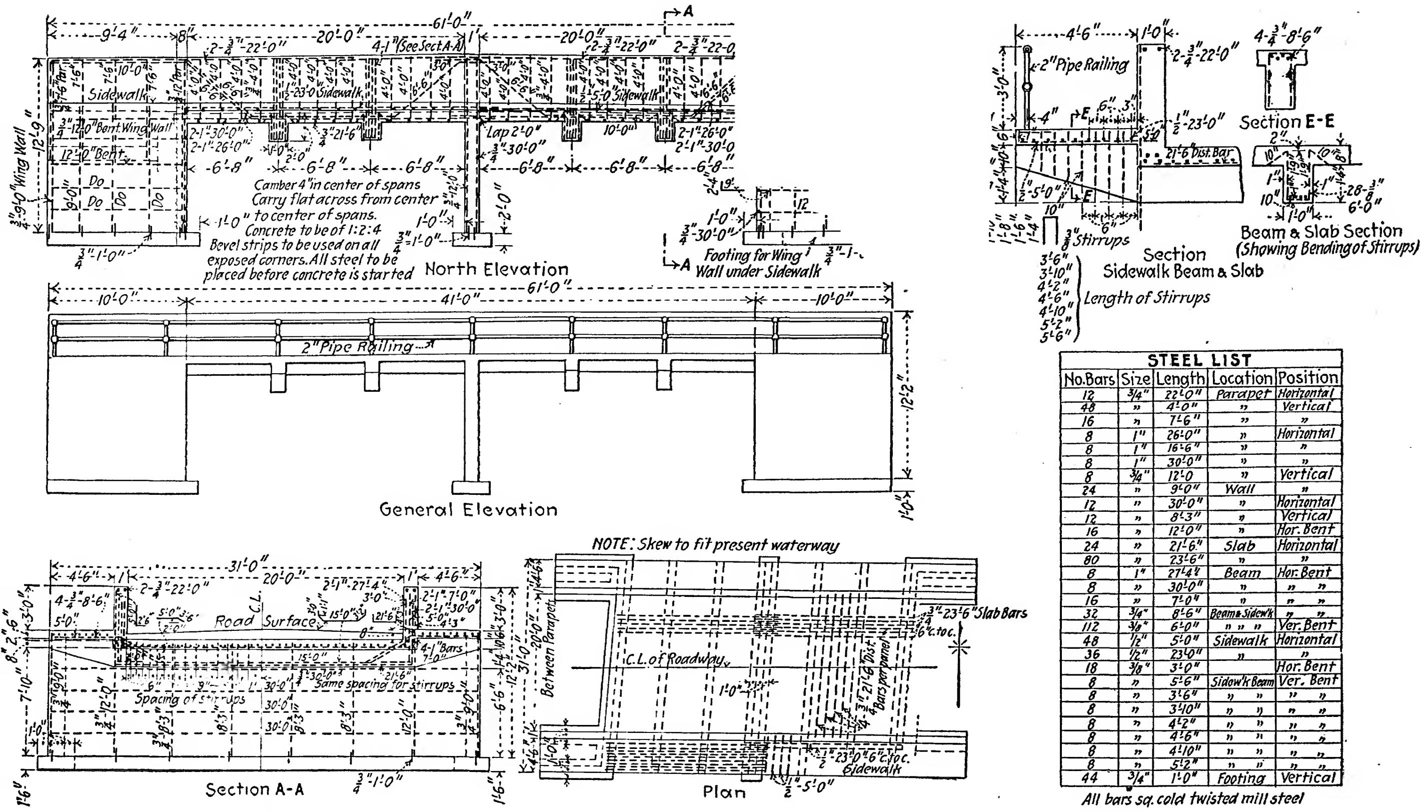


FIG. 126.—Typical reinforced concrete slab. Bridge on soft foundation.



STEEL LIST				
No. Bars	Size	Length	Location	Position
12	3/4"	22'-0"	Parapet	Horizontal
48	"	4'-0"	"	Vertical
16	"	7'-6"	"	"
8	1"	26'-0"	"	Horizontal
8	1"	16'-6"	"	"
8	1"	30'-0"	"	"
8	3/4"	12'-0	"	Vertical
24	"	9'-0"	Wall	"
12	"	30'-0"	"	Horizontal
12	"	8'-3"	"	Vertical
16	"	12'-0"	"	Hor. Bent
24	"	21'-6"	Slab	Horizontal
80	"	23'-6"	"	"
8	1"	27'-4½"	Beam	Hor. Bent
8	"	30'-0"	"	" "
16	"	7'-0"	"	" "
32	3/4"	8'-6"	Beam & Sidew'k	" "
112	3/8"	6'-0"	" " "	Ver. Bent
48	1/2"	5'-0"	Sidewalk	Horizontal
36	1/2"	23'-0"	"	"
18	3/8"	3'-0"		Hor. Bent
8	"	5'-6"	Sidew'k Beam	Ver. Bent
8	"	3'-6"	" "	" "
8	"	3'-10"	" "	" "
8	"	4'-2"	" "	" "
8	"	4'-6"	" "	" "
8	"	4'-10"	" "	" "
8	"	5'-2"	" "	" "
44	3/4"	1'-0"	Footing	Vertical

All bars sq. cold twisted mill steel

FIG. 126A.—Typical reinforced concrete parapet girder bridge on firm soil foundation.

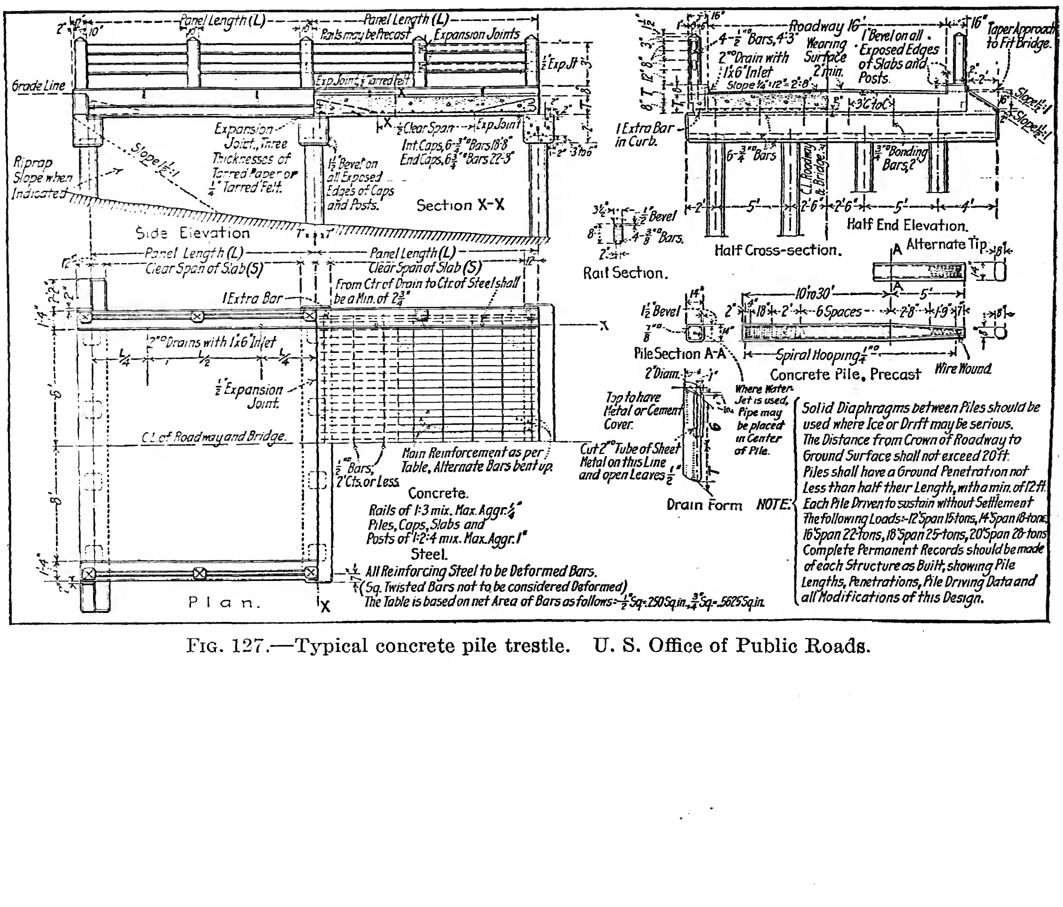
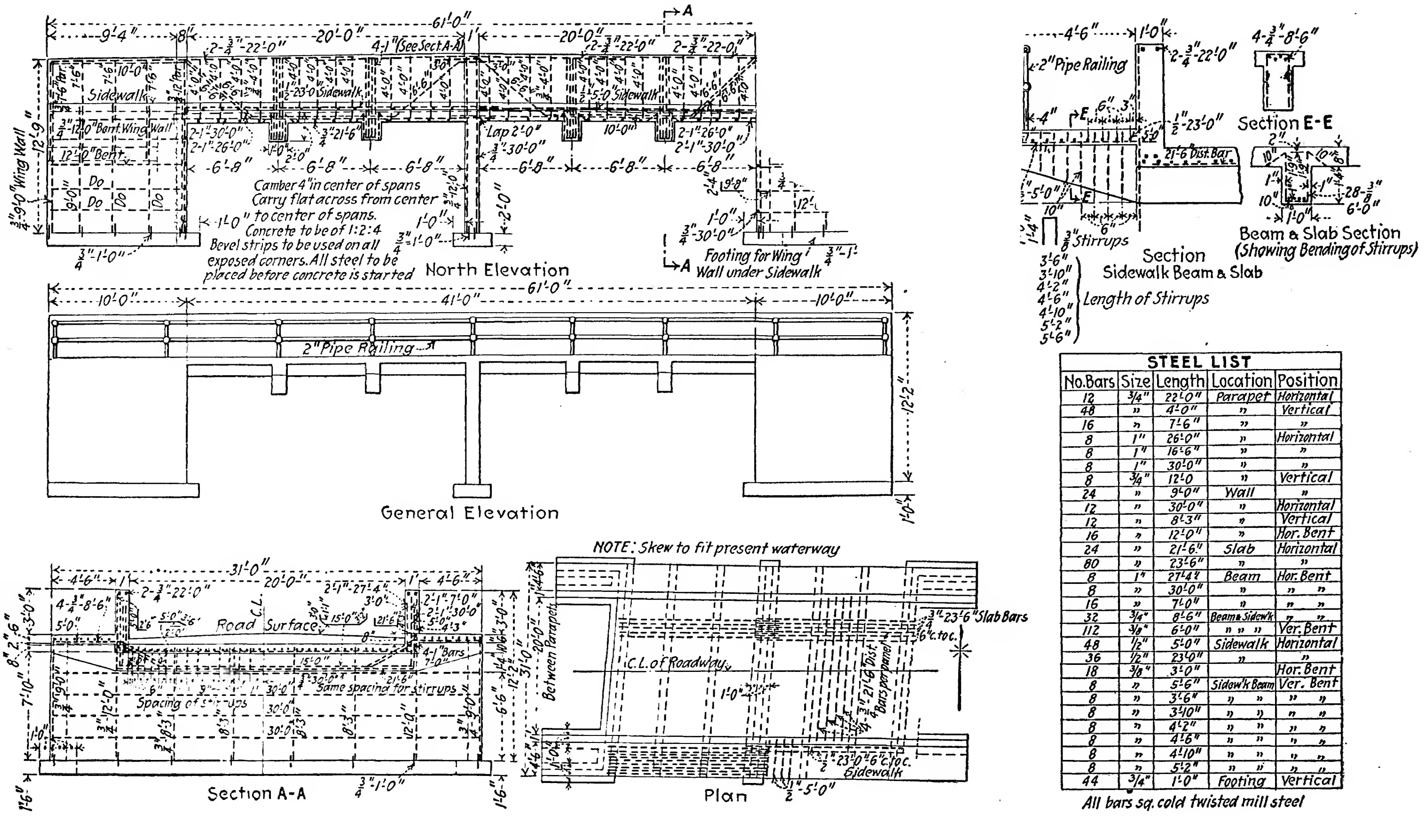


FIG. 127.—Typical concrete pile trestle. U. S. Office of Public Roads.



STEEL LIST				
No. Bars	Size	Length	Location	Position
12	3/4"	22'-0"	Parapet	Horizontal
48	"	4'-0"	"	Vertical
16	"	7'-6"	"	"
8	1"	26'-0"	"	Horizontal
8	1"	16'-6"	"	"
8	1"	30'-0"	"	"
8	3/4"	12'-0	"	Vertical
24	"	9'-0"	Wall	"
12	"	30'-0"	"	Horizontal
12	"	8'-3"	"	Vertical
16	"	12'-0"	"	Hor. Bent
24	"	21'-6"	Slab	Horizontal
80	"	23'-6"	"	"
8	1"	27'-4"	Beam	Hor. Bent
8	"	30'-0"	"	" "
16	"	7'-0"	"	" "
32	3/4"	8'-6"	Beam & Sidew'k	" "
112	3/8"	6'-0"	" " "	Ver. Bent
48	1/2"	5'-0"	Sidewalk	Horizontal
36	1/2"	23'-0"	"	"
18	3/8"	3'-0"		Hor. Bent
8	"	5'-6"	Sidew'k Beam	Ver. Bent
8	"	3'-6"	" "	" "
8	"	3'-10"	" "	" "
8	"	4'-2"	" "	" "
8	"	4'-6"	" "	" "
8	"	4'-10"	" "	" "
8	"	5'-2"	" "	" "
44	3/4"	1'-0"	Footing	Vertical

All bars sq. cold twisted mill steel

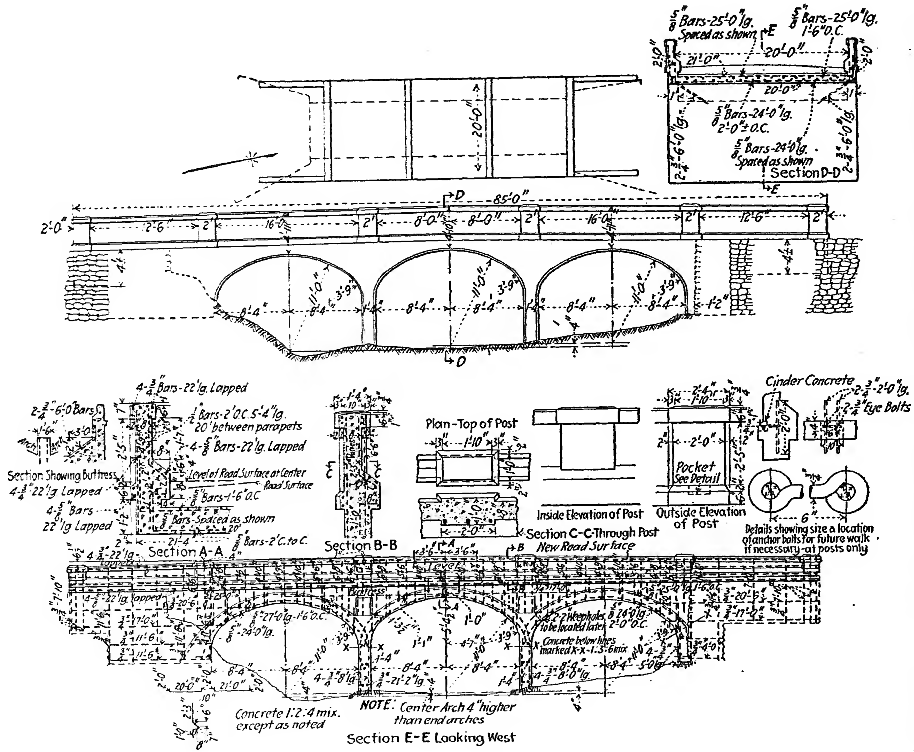
FIG. 126A.—Typical reinforced concrete parapet girder bridge on firm soil foundation.

DIMENSIONS AND ESTIMATED QUANTITIES CONCRETE PILE AND SLAB TRESTLES

Item	Panel Length	Clear Span	Min. Slab Thickness	Reinforcing Steel	Intermediate Panel		End Panel	
					Concrete	Steel	Concrete	Steel
	L	S	T	Main Reinforcement	Cubic Yards	Pounds	Cubic Yards	Pounds
Slabs and curbs...	14 Ft.	12 Ft.	12½ In.	¾" sq. 7" ctrs.	11.46	1070	12.29	1070
	16 Ft.	14 Ft.	14 In.	¾" sq. 6" ctrs.	14.48	1370	15.40	1370
	18 Ft.	16 Ft.	16 In.	⅞" sq. 7½" ctrs.	18.38	1680	19.41	1680
	20 Ft.	18 Ft.	17½ In.	⅞" sq. 6½" ctrs.	22.14	2130	23.26	2130
	22 Ft.	20 Ft.	19½ In.	⅞" sq. 6" ctrs.	26.89	2460	28.13	2460
Railing...........	One rail post				0.0762 Cu. Yd. Concr.		14.45 Lb. Steel	
	One rail (section 3½" × 8") per lin. ft.				0.0072 Cu. Yd. Concr.		1.913 Lb. Steel	
Bents............	One pile 15 feet long				0.67 Cu. Yd. Concr.		174.0 Lb. Steel	
	One pile (section 1'–2" × 1'–2") per lin. ft.				0.0504 Cu. Yd. Concr.		11.6 Lb. Steel	
	One cap for intermediate bent				2.82 Cu. Yd. Concr.		238.0 Lb. Steel	
	One cap for end bent with walls				3.55 Cu. Yd. Concr.		283.0 Lb. Steel	

DESIGN DATA:
Steel in tension, 16,000 lb. per sq. in.
Concrete in compression 600 lb. per sq. in.
Concentrated load, one 15-ton typical truck.
Impact allowance, 30%.
Paving not to exceed 120 lb. per sq. ft.

FIG. 127.—(*Continued*).



STEEL LIST

Number Used	Size	Length	Position	Location
36	5/8	24'-0"	Concentric with Arch	Inside Arch
30	"	25'-0"	"	Outside Arch
15	"	27'-0"	"	" " N.
24	"	24'-0"	Hor.	Inside Arch
18	"	25'-0"	"	Outside Arch
8	3/4	7'-10"	Ver.	Inside End Posts
6	"	11'-6"	"	" Post
20	"	6'-6"	"	" "
16	"	11'-6"	"	Outside Wall
12	"	6'-8"	"	" "
12	"	5'-6"	"	" "
12	"	4'-10"	"	" "
6	"	4'-9"	"	" "
84	1/2	5'-4"	"	Inside Parapet
16	3/4	22'-0"	Hor.	Top of Parapet
8	3/4	22'-0"	"	Outside "
8	5/8	22'-0"	"	Wheel Guard
8	5/8	22'-0"	"	Outside Parapet
4	3/4	20'-6"	"	" Wall
8	"	17'-0"	"	" "
2	"	11'-6"	"	" "
2	"	4'-0"	"	" "
4	"	5'-0"	Ver.	Abutment
16	"	8'-0"	"	Piers
12	"	21'-2"	Hor.	Piers & Abut's.
8	"	6'-0"	Inclined	Buttresses
24	"	2'-0"	Ver.	Posts
24	"	See Detail	Hor.	Posts, 6" c. to c.
4	"	15'-0"	"	Walls, West

SUMMARY-STEEL TO BE ORDERED

No. of Bars	Size	Length	Total
8	3/4"	7'-10"	62'-8"
6	"	11'-6"	69'-0"
20	"	6'-6"	130'-0"
16	"	11'-6"	184'-0"
12	"	6'-8"	80'-0"
12	"	5'-6"	66'-0"
12	"	4'-10"	58'-0"
6	"	4'-9"	28'-6"
16	"	22'-0"	352'-0"
8	"	22'-0"	176'-0"
4	"	20'-6"	82'-0"
8	"	17'-0"	136'-0"
2	"	11'-6"	23'-0"
2	"	4'-0"	8'-0"
4	"	5'-0"	20'-0"
16	"	8'-0"	128'-0"
12	"	21'-2"	254'-0"
8	"	6'-0"	48'-0"
24	"	2'-0"	48'-0"
4	"	15'-0"	60'-0"
	Total=2013'-2"	2013×1.91	=3844 Lbs.
36	5/8"	24'-0"	864'-0"
30	"	25'-0"	750'-0"
15	"	27'-0"	405'-0"
24	"	24'-0"	576'-0"
18	"	25'-0"	450'-0"
8	"	22'-0"	176'-0"
8	"	22'-0"	176'-0"
	Total=3397'-0"	3397×1.33	=4518 Lbs.
84	1/2"	5'-4"	448'-0"
			448×0.85=381 Lbs.
			Total 8743 Lbs.

All bars square twisted mild steel

FIG. 128.—Penfield arch. Details of arch bridge.

types) a design loading of from 10 to 15 tons per pile for sound well driven piles is conservative practice.

The safe load on a pile as actually driven during construction is given in Volume IV.

Scour.—Scour is produced in different soils at approximately the following velocities:

Sand	2 to 3	ft. per second
Loam	2 to 3½	ft. per second
Firm gravel	5 to 6	ft. per second

Rip rap reduces scour and will usually protect the banks from scour up to a velocity of about 12 ft. per second if well placed and made of large stone of ½ cu. ft. or larger volume.

If the natural stream velocity is not greater than 10 ft. per second the span is usually regulated so that the velocity under the bridge will not exceed 10 ft. per second.

2. Longitudinal Drainage.—Longitudinal drainage covers the normal road section ditch, special creek channels, the protection of ditches from scour on steep grades, the use of storm water sewers on long grades, where it is not possible to get rid of the surface water by diversion from the road, and driveway culverts.

Carrying Capacity of Ditches.—It is desirable to use as shallow and small a road ditch as possible both on the score of safety and economy of grading (see Sections page 157). All ditches will clog more or less in the winter with snow and ice so that the size of the ordinary road ditch is more a matter of judgment based on experience than that it is of figures. Intercepting ditches carrying the runoff from considerable areas should be figured using runoffs similar to culvert design methods.

Creek channels and intercepting ditch capacities can be figured. Church's diagrams of Kutter's formulæ using a value of $n = 0.035$ furnish a quick easy method of approximately the required size. Volume III takes up the design methods of determining the volume of flow in small streams.

In order to give a fairly definite idea of the limitations of the use of the shallow and medium road ditches shown in Fig. 67 and reproduced below the following conditions are outlined. As a rule the capacity of the roadway ditch is taxed by short sharp summer showers. As previously discussed it is desirable to use special intercepting ditches if much water flows from the adjacent lands onto the road right of way. Assuming that

this has been done the road ditch proper only carries the water from one-half the road section plus the area of back cut slopes or small areas of farm land. The runoff from the pavement proper is about 80 to 90 per cent. of the rainfall for showers of say 10 minutes duration. The runoff from the shoulders and backslopes is perhaps 60 per cent. under favorable conditions. We can assume an average runoff of about 75 to 80 per cent. of the rainfall for the area of one-half the total right of way width. This means as a rule that the shallow ditch should not be used for more than 400 ft. from a summit or below a ditch relief culvert on flat grades or more than 800 ft. on moderate grades. Current practice recognizes this general principle by the use of deeper and larger ditches in flat country than in rolling country. The medium ditch will serve satisfactorily for at least 2000 ft. from summits provided it does not carry side land runoff.

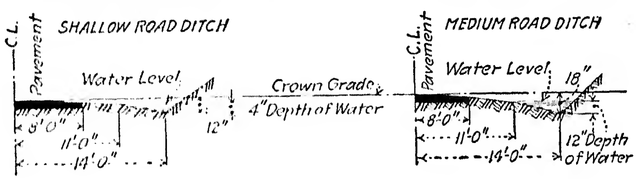


FIG. 129.

To give a rough idea of the carrying capacity of ditches a condensed table is given for a few ordinary cases.

TABLE 34. TABLE APPROXIMATE CARRYING CAPACITIES AND VELOCITIES OF FLOW ORDINARY ROAD DITCHES GRASSED OVER

Grade of road ditch, per cent.	Shallow ditch, Figure No. 129		Medium ditch, Figure No. 129			
			Depth water, 12 in.		Depth water, 6 in.	
	Velocity, ft.	Capacity, sec. ft.	Velocity, ft.	Capacity, sec. ft.	Velocity, ft.	Capacity, sec. ft.
1.0	0.7	0.4	2.0	4.0	1.1	0.5
2.0	1.1	0.7	3.0	6.0	1.7	0.8
3.0	1.3	0.8	3.6	7.2	2.0	1.0
4.0	1.5	0.9	4.2	8.4	2.3	1.2
5.0	1.7	1.0	4.8	9.6	2.6	1.3
6.0	1.8	1.1	5.3	10.6	2.8	1.4
7.0	2.0	1.2	5.6	11.2	3.1	1.5
8.0	2.2	1.3	6.0	12.0	3.4	1.7
9.0	2.3	1.4	6.5	13.0	3.6	1.8
10.0	2.5	1.5	7.0	14.0	3.8	1.9

Protection of Ditches from Scour.—The rate of grade at which ditch protection from scour is advisable depends on the soil and velocity of flow; the velocity of flow depends on the shape of ditch and volume of water.

Soils scour at approximately the following velocities:

Sand	2 to 3	ft. per second
Loam	2 to 3½	ft. per second
Firm gravel	5 to 6	ft. per second

Foregoing Table 34 is inserted to show in a general way the effect of shape of ditch and depth of flow on velocity and indicates that ditch protection must be provided at lower rates of grade for a large flow than for a small flow. This agrees with current practice which favors the use of cobble or cement gutter at approximately the following rates of grade.

Current Practice in Ditch Protection.—Where the volume of flow is less than 1.0 sec. ft. ditch protection is not needed on hills less than 7 per cent. grades. Where the volume of flow

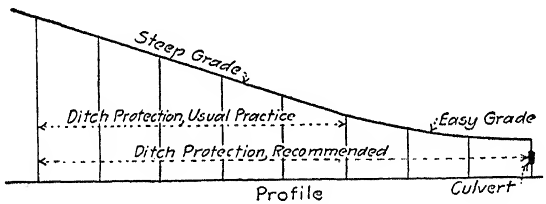


FIG. 130.

exceeds this amount ditch protection is advisable on sandy or loam soils on grades steeper than 3 per cent. and in firm gravel on grades of 5 per cent. or greater. This means that as a rule on steep grades some kind of gutter is desirable for ditches more than 200 to 300 ft. from a summit or below a ditch relief culvert. It is practically impossible to carry a large volume of water down a steep grade so that every effort should be made to divert the flow above the grade or remove it from the surface by ditch relief culverts or storm sewers.

Where ditch protection is used it is good practice to carry it for at least 200 ft. along the road after the foot of the steep grade is reached and preferably to the first culvert below the grade in question as scour often occurs through stopping the protection too closely to the bottom of the steep grade.

Cobble gutter with cement joints on grades over 6 per cent. and sand or gravel joint filler on grades less than 6 per cent. where the volume of flow is not large is probably the best design as it tends to retard the velocity of flow.

The smooth concrete ditch lining is not usually satisfactory on steep grades but is allowable if the cobble gutter is not available.

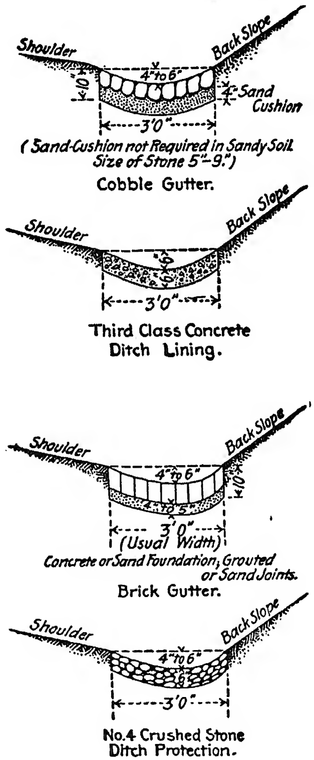


Fig. 131.

Storm Sewers on Hills.—Where it is impossible to divert the water from the surface on long hills a storm sewer system is sometimes used.

Catch basin inlets are constructed at intervals of 200 to 400 ft.

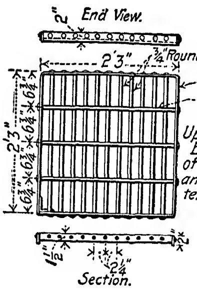
The size of pipe are figured for probable runoff in the same manner as for culverts. Table 35 given below gives a rough approximation of the carrying capacity of different sized pipes laid on different grades.

TABLE 35.[1]—APPROXIMATE FLOW CAPACITY IN CUBIC FEET PER SECOND
Value of $N = 0.013$

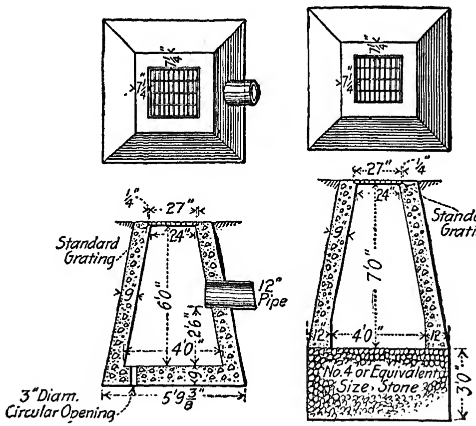
Grade, per cent.	Capacity of flow of different sized pipe					
	12 in.	15 in.	18 in.	20 in.	24 in.	36 in.
0.5	2.4	4.4	7.5	9.5	16.0	42.0
1.0	3.3	6.3	10.5	14.0	23.0	60.0
1.5	4.2	7.6	13.0	17.0	27.0	75.0
2.0	4.8	8.8	15.0	19.0	31.0	86.0
3.0	5.8	11.0	18.0	24.0	39.0	105.0
4.0	6.5	13.0	22.0	27.0	46.0	122.0
5.0	7.3	14.0	24.0	30.0	51.0	137.0
6.0	8.1	15.0	26.0	33.0	56.0	150.0
7.0	8.8	16.0	27.0	35.0	60.0	162.0
8.0	9.5	17.0	28.0	38.0	65.0	173.0

[1] Computed from diagram Ogden's Sewer Design.

Figures 132 and 133 give typical catch basin and simple manhole designs for such a sewer.



Wrought Iron.
FIG. 132.



Manhole. Leaching Basin.
FIG. 133.

Driveway Culverts.—Culverts under drives cause more drainage troubles than any other feature as they are usually constructed by the property owner instead of being included in the road contract.

It is an amusing fact that private farm bridges over streams or road ditches are notoriously small. Each owner seems to

think that water will get under his drive in a small cheap structure and the same man who says that a road structure is too small will build a bridge or driveway sluice just below this structure that he has been kicking about and make it from 1/10 to 1/2 as large as the main drainage structure unless he is prevented by law which is enforced by highway officials.

The size of the structures should be fixed on the road plan and designed from the same standpoint as a culvert or bridge.

Cheaper types of structure are suitable as they can be readily replaced without tearing up the pavement.

Corrugated metal pipe, vitrified tile or reinforced concrete tile are suitable but no matter how little water is carried the size of driveway culvert should not be less than a 12 in. pipe on account of maintenance difficulties. These culverts are properly placed in the ditch line at normal ditch grade and as a rule 12 ft. length is about the minimum that will be at all satisfactory.

Underdrainage.—The purpose of underdrains on hard surfaced roads is to intercept the ground water before it reaches and softens the sub-grade. On a sidehill road the drain is usually

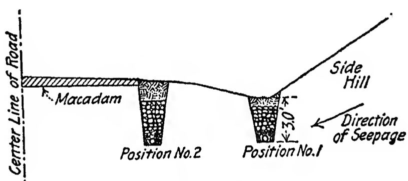


FIG. 134.

placed under the ditch on the uphill side (see Fig. 134, position No. 1) where the greatest depth can be obtained with the last excavation and where the water is caught as it flows out of the hill.

Some engineers place the drain in position No. 2 (Fig. 134) but this requires more excavation for the same depth and for side seepage is not as effective. The usual depth for drains is 3 ft. to 4 ft. below the surface.

Where the road is on a descending grade, the water will flow out of the hill directly under the stone and the drain is placed as in Fig. 135, position 1, or two drains are built in position No. 2. Position 1 is the usual practice, being cheaper and more effective.

The argument for the two side drains is, that in case the throat becomes clogged, a side drain can be taken up without disturbing the macadam. This rarely occurs in a center drain, as it is better protected than those in position 2 and in case the center drain does clog, side drains can be constructed at any time.

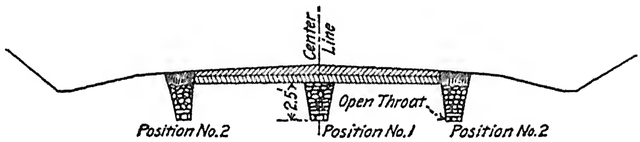


FIG. 135.

There are two kinds of drain in general use, Fig. 136:

No. 1 is built entirely of stone with an open throat roughly laid as shown; it is satisfactory in a water-bearing strata of gravelly loam of clay, but does not work so well in quicksand, iable to fill it up. It is generally cheaper, however, 2.

s built of porous farm tile or vitrified tile of a suitable ally 3 in. to 6 in.) with open joints, wrapped with a double or triple layer of burlap; the pipe is surrounded and covered with clean gravel or ¾ in. crushed stone to a depth of 6 in., the remaining depth of the trench being filled with large stone. If this drain has a good fall and the outlet is kept free, it will rarely clog even in bad quicksand.

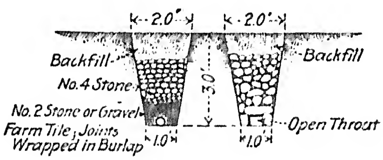


FIG. 136.

The following method has been successfully used to prevent the outlet from clogging; after being brought out from under the macadam, the drain is continued under and across the ditch line, then keeping outside the ditch line, and using a slightly smaller gradient than that of the open ditch, the tile is continued down the hill until it reaches a point eight or nine inches above the ditch grade. Here it is turned into the open ditch through a small concrete head-wall and what little material

it tends to deposit is washed down the ditch by the surface water (see Fig. 137). The lowest rate of grade advisable for underdrains is 3 in. per 100 ft.

Summary of Chapter.—The present bridge situation demands attention as even in the richer states it is lagging behind the improvement of the roads. The separation of bridge and highway funds and the lack of central control often results in the ridiculous situation of a modern road limited in use by antiquated bridges.

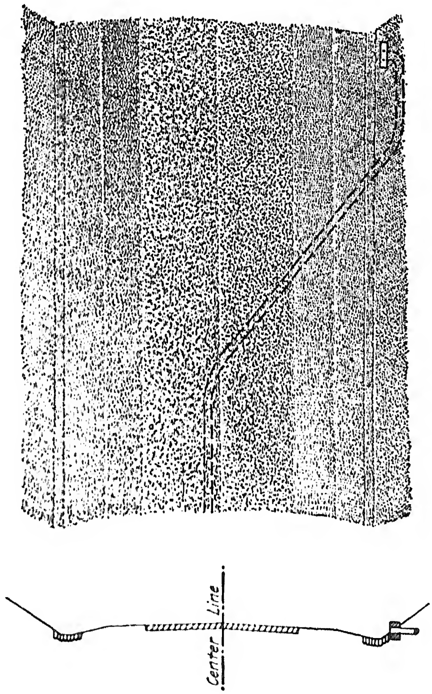


FIG. 137.

Road pavements can be strengthened from year to year by additions in thickness and the construction of better surfaces on top of existing improvements but structures must be rebuilt entire to increase their strength and for this reason more foresight in regard to future traffic must be exercised in their design. A liberal allowance for increased loads is desirable. Liberality in size of waterway for culverts is also good policy as it adds

only slightly to the cost and materially decreases the difficulties of maintenance.

The design of drainage must be complete and reasonable and if the existing scheme is not feasible it should be changed regardless of law-suits as whenever an improvement is made it is always cheaper to correct mistakes at that time than it will be at a later date as every year's use fix the channels more firmly.

The selection of type offers the greatest chance for reasonable economy in culvert and bridge design.

CONCLUSION OF VOLUME I

The discussion of location, grades, alignment, section and drainage in this volume covers the permanent elements of highway construction. These parts of the design deserve more liberality and foresight in their treatment than the design of the pavement surfacing and other minor features of a complete road plan.

Volume II considers the temporary elements of construction namely the economical selection and design of pavements; methods and cost of maintenance and the problems met in the reconstruction of worn out pavements. The reasons for making a separate volume of pavement design are that road surfacings are a specialized subject in themselves; the problem is approached from a somewhat different angle than used in this volume and practice in pavement construction is changing so rapidly that frequent revisions will be necessary to keep abreast of approved practice. We believe by making "pavements" a separate volume which will by necessary revisions be kept up to date that we will give our readers better continuous service with less cost to them and to ourselves than if we had combined Volumes I and II into one book.

This book (Volume I) covers comparatively stable practice. Volume II is well along in preparation and will be on the market in a short time.

APPENDIX A. HIGHWAY BONDS[1]

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Before a community invests its money in improved roads it is important that plans be made for the ultimate development of a complete system fully adequate to serve its needs most economically. The making of such plans and the selection of the particular road or roads to be improved should be based on sound business principles. Careful consideration should be given to the traffic area which the contemplated improvements are to serve; the present and probable future traffic in ton-miles per annum; the estimated cost of hauling per ton-mile at present and what it probably will be reduced by the improvement; the roads which should be improved first; the approximate cost of the improvement as borne out by the surveys and estimates made by a competent highway engineer; the probable effects of the improvement on farm values, school consolidation and attendance, community betterment and rural delivery of the mails; whether the work can be carried on by direct taxation or whether it is desirable to resort to credit; and if borrowing is necessary, the best and most economical method of financing.

As a high standard of public credit is an asset of great value, every community should conduct public business upon sound financial principles. Bond issues ought to be resorted to only when they cannot be avoided. If a county, township or district is able to levy a sufficient tax to improve all of the roads required in a reasonable length of time without imposing too great a burden on the taxpayers, it should by all means adopt this course. It is also axiomatic that maintenance charges for roads and other current expenses should always be met from the proceeds of an annual tax levy.

Comprehensive study of the community's road problems should make possible a wise decision as to the character and extent of the needed improvement. If the people deem it advisable to issue bonds and distribute the burden over a period of years, then they should determine with careful forethought what kind of bonds should be issued, whether long or short term, whether sinking-fund or serial bonds, and what taxes should be imposed to extinguish the debt.

The life or term of a bond issue should be determined not only by the character of the improvement to be financed, but also by the ability of the county, township or district to dispose of the debt as quickly as possible without imposing too great a burden upon the taxpayers. The indebtedness should be liquidated at a rate at least equivalent to the depreciation of the improvements thus financed. The payments should be so distributed over a period of years as to avoid the two extremes of excessive or confiscatory levies on the one hand to pay off the debt too quickly and the extension on the

[1] Revised by The National City Company, New York.

other hand of the debt beyond the life of the utility, in order to obtain a low annual tax rate. Sudden and rapid changes of tax rates are to be avoided.

Recognizing the soundness of the principle of limiting the term of such bonds to the life of the improvement, New Jersey and Delaware have expressly imposed such limitations by statute. In some other States the maximum term of public road bonds has been limited to 15 years, even though the roads constructed are the most permanent and durable that is possible to build.

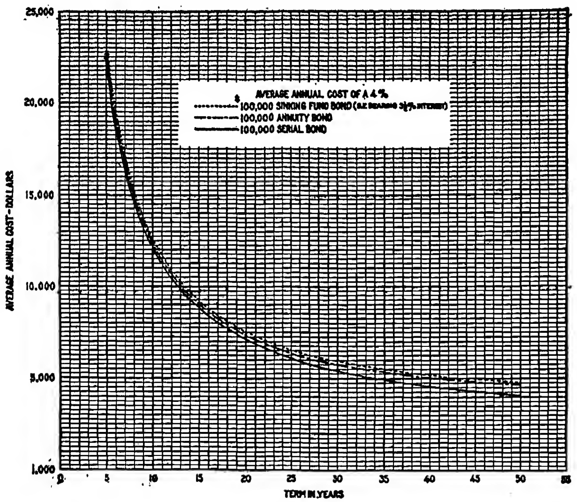

Fig. 1.—Little advantage is gained through bonds running more than 25 years.

The New Jersey law may, perhaps, be cited as a model illustration of the principle. This law limits the term of public road bonds as follows: For stone, concrete and iron bridges, 30 years; for roads and streets built of concrete 6 in. thick or of block of any material or sheet asphalt laid on concrete foundation, 20 years; for bituminous concrete construction, 15 years; for waterbound macadam, penetration method, 10 years; and for gravel, 5 years.

Many road bonds are issued for terms of 30 years and over to obtain a low annual charge for interest and principal. Very little advantage, as is shown graphically in Fig. 1, is to be gained by fixing the term of the bond longer than 25 or 30 years. The cases are probably not numerous where even a much shorter term would necessitate an annual tax levy which would be considered excessive. It is obvious that the character of the improvement will sometimes make the shorter term issues more or less imperative, either on general principles or to comply with statutory requirements.

Corollary to the above principles is adequate provision for maintenance of the improvement during its life. The importance of maintenance is so

great that statutes authorizing bond issues for construction should require, as part of the stipulations under which the bonds are issued, an adequate financial provision for the upkeep of roads during the term of the bonds. This insures a more complete statement of the financial obligations of a bond issue before taxpayers vote on the issue. Maintenance provisions will care for depreciation, but not for obsolescence which must be considered in fixing the terms of bonds for such improvements as bridges.

Theoretical discussion of the types of bonds suitable for road improvement financing usually includes sinking-fund, annuity and serial bonds. Practically, however, the annuity bond serves a purpose similar to the serial bond, costs slightly more, and has little favor either among bond dealers or the investing public. These considerations are deemed so important that the further discussion of this type has been omitted.

Under the sinking-fund plan, none of the bonds issued are retirable until the end of a definite period and the entire sum raised bears interest for the entire life of the bond. The county or municipality pays interest on the

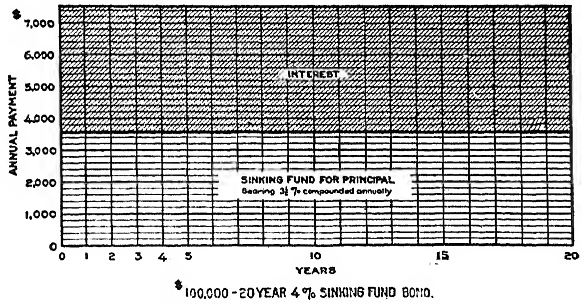

FIG. 2.—Sinking fund bonds bear interest on full sum for whole life.

money so borrowed and in addition sets aside each year, as a sinking fund, an amount which invested at compound interest will be theoretically sufficient to retire all the bonds when they become due. The rate of interest usually compounded on the sinking fund is low in comparison with the interest paid on the bonds.

The method of disposing of a 20-year sinking-fund bond is shown graphically in Fig. 2.

Under the serial plan a certain amount of the bonds is retired each year, the interest on the remaining amount outstanding is paid and the bonds retired cease to be an interest charge on the community. The straight serial method would require the heaviest payments for interest and retirement of principal in the early years of the term issue, often before the improvement is fully completed or before it has yielded the community any return. To meet these conditions which frequently arise in road districts, the use of the deferred serial bond has become common. With such a modified type no principal is retired until a certain period, usually five years, has elapsed. During this period interest is paid but nothing more. There-

after the principal is retired by uniform amounts and the interest charges are met just as is the case of straight serial bonds having a term shorter by five years, or whatever is the deferred period. In this way the road district need not pay anything but interest until the improvements have begun to yield a return.

The straight serial method of payment is graphically shown in Fig. 3.

For road improvements the serial bond is preeminently the most desirable type. The reasons for its special desirability may be briefly stated:

(*a*) The serial bond minimizes the dangers involved in the administration of a public debt. The serial bond requires annually a specified payment of both principal and interest direct to the bondholder. Both principal and interest must be met out of the annual tax levy. If the principal payment required is not met, there is a public default and community credit is seriously injured, if not ruined. The serial bond makes absolutely certain gradual retirement of the public debt.

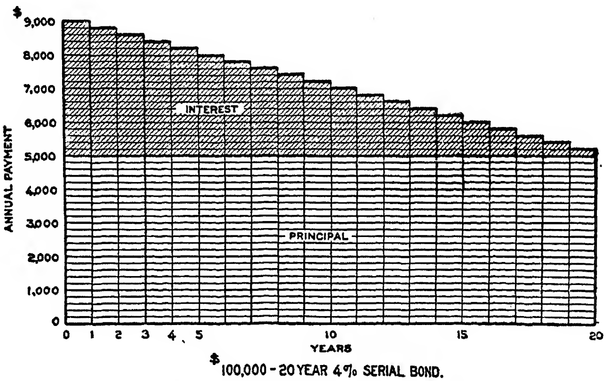

FIG. 3.—Serial bonds lessen interest payments.

Under the sinking-fund plan specified payments for retirement of principal must be made to a fund, custody of which is usually vested in public officials, until maturity of the debt. Furthermore, the sinking fund must be administered so as to earn compound interest. Unfortunately the financial methods of public officials do not always remain above criticism and it often happens that the annual payment into the sinking fund is forgotten or neglected, no matter how much such contingencies may have been legally safeguarded. Sometimes the money accumulated in the sinking fund is diverted from its purpose. Such departures from sound finance result in lack of money to pay off the bonds when they become due, as agreed, and it then becomes necessary to issue a new series of bonds to carry the indebtedness. The history of the administration and use of municipal sinking funds afford abundant testimony of its dangers. Generally, for most minor civil districts, it may be said to be an antiquated and undesirable fiscal method. Until a few years ago sinking-fund bonds were almost universally used. Realizing the economy of serial issues, about 10 states now require serial issues for road improvement issues.

(*b*) The serial bond is the cheapest form of bond financing. Figure 4 presents the relative cost of the different types of bonds graphically and Table I presents the actual cost comparison between sinking-fund and serial bonds.

(*c*) Undoubtedly the serial bond maturing within the life of the improvement is the most popular bond for private investors and institutions. A great many investors will not buy a bond maturing in more than 10 years. Serial bonds are attractive because they give the investor an opportunity to buy bonds which will meet practically all his requirements as to length of time of his investments. For instance, a man may have \$4000 or \$5000 in

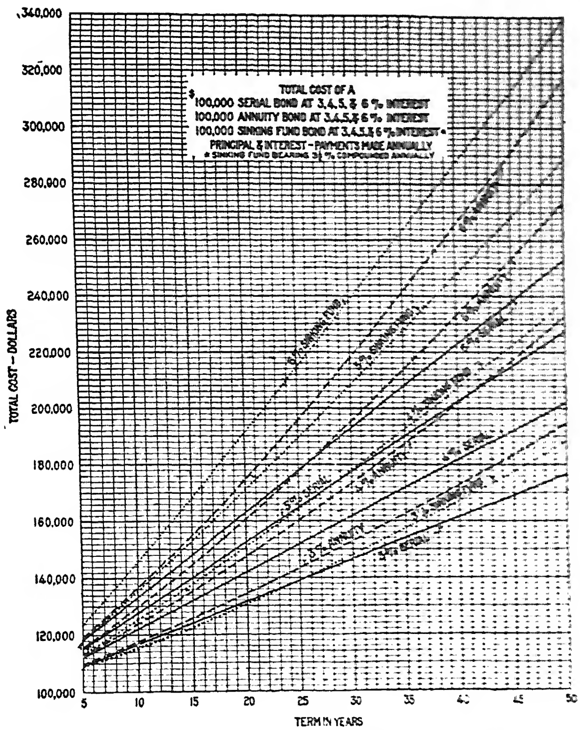

FIG. 4.—Relative cost of different bond types.

the bank at a low rate of interest and wants to [illegible] he accumulates a given sum, say in about 6 years. He [illegible] 6-year serial bond. The same may be true in any [illegible] only with private investors, but also institutions. When [illegible] low, banks are heavy buyers of short term maturities, say [illegible] bonds. When money rates are high and as a consequence [illegible] the long term bond appeals to the investor. Generally, serial [illegible] investors to put out their funds in a more satisfactory manner. [illegible]

can sell them more readily and may, consequently, be able to reduce his bid slightly.

The management of a bond issue requires attention to all the requirements of the laws governing such matters and a knowledge of the conditions which affect the value of bonds. Every step which the law requires to be taken in connection with such bonds must not only be taken properly but recorded fully and clearly. As soon as the voters authorize the issue, a statement of the fact should be drawn up, showing also the area, population and assessed valuation of the district, the value of its agricultural and

Table I.—Comparative Cost—Sinking Fund and Serial Bonds

Average annual cost of a $100,000 sinking-fund bond bearing 3, 4, 5 or 6 per cent interest, with sinking fund drawing 3½ per cent interest, and bonds maturing at different periods from 5 to 50 years.

Term in Years	3%	4%	5%	6%
5	$21,648	$22,648	$23,648	$24,648
10	11,524	12,524	13,524	14,524
15	8,183	9,183	10,183	11,183
20	6,536	7,536	8,536	9,536
25	5,567	6,567	7,567	8,567
30	4,937	5,937	6,937	7,937
35	4,500	5,500	6,500	7,500
40	4,183	5,183	6,183	7,183
45	3,945	4,945	5,945	6,945
50	3,763	4,763	5,763	6,763

Table II

Average annual cost of a $100,000 serial bond bearing 3, 4, 5 or 6 per cent interest, and maturing at different periods from 5 to 50 years.

Term in Years	3%	4%	5%	6%
5	$21,800	$22,400	$23,000	$23,600
10	11,650	12,200	12,750	13,300
15	8,267	8,800	9,333	9,866
20	6,575	7,100	7,625	8,150
25	5,560	6,080	6,600	7,120
30	4,883	5,400	5,917	6,434
35	4,400	4,914	5,429	5,943
40	4,037	4,550	5,063	5,576
45	3,756	4,267	4,778	5,289
50	3,530	4,040	4,550	5,060

TABLE III.—TOTAL COST OF SINKING FUND BOND

Total cost of a $100,000 sinking-fund bond bearing 3, 4, 5 or 6 per cent interest, with sinking-fund drawing 3½, and maturing at different periods from 5 to 50 years.

TERM IN YEARS	3%	4%	5%	6%
5	$108,241	$113,241	$118,241	$123,241
10	115,241	125,241	135,241	145,241
15	122,738	137,738	152,738	167,738
20	130,722	150,722	170,722	190,722
25	139,185	164,185	189,185	214,185
30	148,114	178,114	208,114	238,114
35	157,494	192,494	227,494	262,494
40	167,309	207,309	247,309	287,309
45	177,540	222,540	267,540	312,540
50	188,169	238,169	288,169	338,169

TABLE IV.—TOTAL COST OF SERIAL BOND

Total cost of a $100,000 serial bond bearing 3, 4, 5 or 6 per cent interest and maturing at different periods from 5 to 50 years.

TERM IN YEARS	3%	4%	5%	6%
5	$109,000	$112,000	$115,000	$118,000
10	116,500	122,000	127,500	133,000
15	124,000	132,000	140,000	148,000
20	131,500	142,000	152,500	163,000
25	139,000	152,000	165,000	178,000
30	146,500	162,000	177,500	193,000
35	154,000	172,000	190,000	208,000
40	161,500	182,000	202,500	223,000
45	169,000	192,000	215,000	238,000
50	176,500	202,000	227,500	253,000

industrial products, its material resources and the extent of their development, the banking and transportation facilities serving it, the existing indebtedness of the district, the condition and number of the schools, and all other information which will indicate the resources and character of the community that has decided to borrow the money. This information should be sent to banking houses and insurance companies making a specialty of purchasing public bonds and, if the issue is a large one, it should be advertised in financial journals. There should be ample time between the publication of these notices and the sale of the bonds for purchasers to make a full investigation of them.

[1] Private sales of bonds for public works should be discouraged, all sales of bonds should be publicly advertised, and bidders should be invited to submit sealed bids on or before a certain date. The bonds should be sold to the highest responsible bidder who complies with all of the terms and conditions of the sale. The city or county should reserve the right to reject any or all of the bids, as a protection against any effort to pool bids and purchase the bonds at a price considerably less than their value.

Some cities and counties engage competent attorneys, familiar with the preparation of the legal papers pertaining to bond issues, to examine the records prior to the sale and prepare all necessary forms. The city or county assumes the expense for all such work and furnishes the successful bidder with the approving opinion of the counsel thus engaged and with the executed bonds. Some cities and counties go even further by providing uniform proposal blanks for the bonds and refusing to accept bids not made on such blanks. The advantage of these provisions is that the seller knows he is offering a legally and validly issued bond, the buyer has the same assurance, and the value of the issue is certainly enhanced thereby. The seller is undoubtedly reimbursed for the expense incurred in such preparatory work by the price he receives for the bonds.

paragraph were prepared by Baker, Watts & Company.

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General Note.—The page references are given in their order of importance. The first reference will usually cover the most used data.